Were burnt moulds derived from prehistoric copper production activities?

Thelin, Virginia H.

WERE BURNT MOUNDS DERIVED FROM PREHISTORIC COPPER PRODUCTION ACTIVITIES?

by

Virginia H. Thelin

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ABSTRACT

Burnt mounds and copper arrived on the scene in the British Isles at about the same time, at the beginning of the Neolithic to Bronze Age transition in the mid-3rd millennium BC. Burnt mounds disappeared from that scene when iron was in process of replacing copper as the pre-eminent metal of the British Isles by about 500BC. Are burnt mounds and copper, then, directly related? Specifically, were burnt mound sites locations where some or all of the stages of the earliest forms of copper production took place? The research described in this paper is an initial attempt to find out.

The first three chapters review and examine what is known both of burnt mounds in the British Isles and of the earliest copper production, the latter mainly from other parts of the world, since so few early copper processing sites have yet been discovered in the British Isles. Chapter 3 also compares features found at burnt mound sites with the requirements of early copper production, as far as they are known.

In Chapters 4 and 5 attempts are made to test, by geochemical and geographic means, whether there is a direct relationship between burnt mounds and copper production. In Chapter 4, EDXRF is used to determine concentrations of copper and other elements in three burnt mounds, and in Chapter 5 known locations both of burnt mounds and copper sources are mapped and compared to find out whether burnt mounds are grouped close to copper sources.

Chapter 6 evaluates the overall results and recommends a variety of additional types of research to more closely approach an answer to the title of this paper.

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Virginia H. Thelin: Virginia H. Thelin

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V.H.T.

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Chapter 1

INTRODUCTION TO BURNT MOUNDS AND PLAN OF RESEARCH

Burnt mounds are among the most numerous of all the types of prehistoric monuments in the British Isles. More than 4,500 are known in Ireland (Power *et al.* 1992, 75) and there are around 4,000 more in the United Kingdom. They are also among the most enigmatic of prehistoric remains, as the purpose they served has not been definitively determined. Nevertheless, burnt mounds are possibly the most neglected of the major classes of prehistoric monuments, certainly by tourists, but also in university lectures and textbooks, and perhaps in terms of research as well.

There are five features which are characteristic of burnt mounds in general, although none are possessed by all burnt mound sites without exception.

- The mound itself is composed of fire-cracked stones in a matrix of soil and charcoal, and is often crescent-shaped.
- The location is almost always beside a stream, an old stream bed, or in wet, boggy ground.
- When excavated, a trough is usually found, often under the hollow between the arms of the crescent which faces the stream. The trough is generally a steep-sided, flat-bottomed pit, apparently designed to hold water.
- A hearth, a place on the ground where repeated burnings appear to have occurred, is often found near the trough.
- If the mound is radiocarbon-dated, it usually dates to the Bronze Age.

Various theories have been advanced as to what Bronze Age people were doing at these sites. At minimum, stones were being heated in a fire and water was apparently placed and maintained in the trough. At some point the water and hot stones likely came in contact with each other, probably for the purpose of heat transfer; i.e., either heating the water (possibly to turn it into steam), or rapidly cooling the stones. The most generally accepted theory holds that the trough was used for cooking by first filling it with water, then continually adding heated stones and eventually food, keeping the water boiling until the food was ready to eat. A contending theory suggests that the burnt mound sites were saunas, where water was thrown on hot stones which had been removed from the fire, producing clouds of steam. A number of other theories of possible burnt mound site function will be mentioned in the course of the following review of the development of burnt mound research over the past two centuries.

A Short History of Burnt Mound Research

The 19th Century

Perhaps the first scholarly work to deal with burnt mounds was a book by Walter Davies (1810, 41), on the economy of north Wales. Since mines played a large role in the economy of north Wales, it is not surprising that Davies referred to burnt mounds as "the ancient British smelting-hearths, where the ore and the wood-fuel were intermixed". He also noted "wherever these ancient hearths are found the vicinity is a favourable field for mine adventurers" and that "the scoriae of some of the hearths are more perfectly reduced than those of others". Davies was not an archaeologist, but, judging by his vocabulary, he did know something about metallurgy.

Southern Ireland may have more burnt mounds than any other similarly-sized area on earth, so it is fitting that antiquaries of southern Ireland were the first to report their findings from burnt mound investigations at archaeological society meetings. They probably were not aware of Davies' book, but they had been steeped in Irish legends which portrayed burnt mounds as cooking places where feasts had been prepared, and they therefore assumed that this had been the major function of the sites. They also knew that similar cooking methods were used by indigenous people in some other parts of the world. The first of these investigators was William Hackett (1855), who described the major features of burnt mounds and claimed for his group of south Munster antiquaries the honour of having discovered, and named, the trough as an essential part of these sites. Unusually, in his part of Ireland, this feature was often found in the form of a hollowed-out half-log for which "trough" was an appropriate name, while perhaps "vat" or "tank" would have been better suited to those generally found elsewhere. He also noted the lack of any tools or weapons at the burnt mound sites he had explored.

Later, M.L. Trench (1886) drew together information on burnt mounds from several sources and noted that, according to ancient tradition, the troughs of burnt mounds were used for washing as well as cooking. The cooking method he described did not seem to involve water, and resembled roasting more than boiling. In the same volume of the same journal, John Quinlan (1886) presented a plan and rudimentary section drawing for a burnt mound he excavated, and emphasized that such sites are always found beside streams (or what were streams in ancient times), and that they are frequently close to the spring from which the stream issues. All three of these writers noted that the local people in County Cork referred to burnt mounds by a Gaelic term which approximated "fulachta fiadh", (interpreted variously by different authors, but apparently related to deer, hunting, and roasting) by which name they are still known today in Ireland (but not elsewhere). In summary, then, 19^{th} century Irish antiquaries generally set the standards followed up to the present time for the characteristic features, much of the terminology, and the most accepted explanations of function for burnt mound sites.

Early to Mid 20^{th} Century

In the early decades of the 20^{th} century burnt mound research spread from Ireland, first to Wales, and then to England and Scotland. The most important researcher of this period was T.C. Cantrill, who (together with O.T. Jones) carried out two surveys of burnt mound sites in south Wales, locating a total 271 mounds (Cantrill and Jones 1906 and 1911). Having established the field survey as a major form of burnt mound research and demonstrated the abundance of burnt mounds in Wales, Cantrill turned his attention to the rest of Britain. He declared that burnt mounds were found "from the Shetlands to the English Channel" and mentioned several which had been identified in Shetland, Sutherland, Berwickshire, East Lothian, the Isle of Man, South Staffordshire, North Warwickshire, Hampshire and East Devon (Cantrill 1913, 648). A later article described five burnt mounds he discovered northeast of Shrewsbury (Cantrill 1916).

At about the same time, back in Ireland, Gordon Forsayeth had excavated a couple of apparent burnt mounds in Ballygambon and, finding no animal bones or hollow-log troughs, concluded they were probably not cooking-places, but rather steam-produced sweat baths (Forsayeth 1911).

In the 1920's more mounds were being discovered in England, and some of them excavated. Nina Layard described at least five burnt mounds in Buckenham Tofts Park, Norfolk, where the burnt stones were all flint (as they later proved to be generally in Norfolk and across much of southern England), rather than sandstone or other materials, as elsewhere. She also found worked flint tools and animal bones at the sites, both unusual finds (Layard 1922). In Sutton Park, Warwickshire W.L. Bullows investigated six closely-situated heaps of burnt stones, where two mounds appeared to contain troughs and the remaining four, hearths (Bullows1927). Both Layard and Bullows created simulated burnt mound sites and found that food could be cooked in them, perhaps the first to do so.

The decades of the 1930s and 1940s seem to have been largely a hiatus in terms of burnt mound research, probably due to world conditions of depression and war. However, the Royal Commissions continued their work of cataloguing many types of sites, including burnt mounds. K.A. Gustawsson (1949, 165) noted that ale had been brewed in Sweden in 1906 under conditions approximating those of a burnt mound.

In the 1950s the focus of burnt mound research shifted back to Ireland. A highly influential article by M.J. O'Kelly (1954) described excavations of five burnt mounds in Co. Cork, and the reconstruction of one of the sites to test its usability for cooking. The special value of this article lies in the exceptional state of preservation of the site chosen for reconstruction, its unusual complexity, and the extremely meticulous excavations and report. As mentioned above, others had previously claimed to have proved that food could be cooked at a burnt mound site, but had not described in much detail how it was done, as O'Kelly did. For many readers the article must have removed any doubt that burnt mounds indeed had been cooking-places. In addition, radiocarbon dating was carried out on two of O'Kelly's sites, giving dates of Early to Middle Bronze Age – perhaps the first burnt mound C^{14} dates obtained. Several other Irish archaeologists made notable contributions at this period as well, including H.W.M. Hodges (1955) who found and excavated three burnt mounds in Ballycroghan while searching for a bronze-smith's workshop near the find-site of three partly-manufactured Bronze Age swords; also Ellen Prendergast (1955) who discovered 16 burnt mounds in Co. Kilkenny, excavating three of them; and E. M. Fahy (1960) who excavated a complex site at Drombeg, Co. Cork which included a burnt mound.

Later 20th Century

From the 1960s through the 1980s there was a steady increase in burnt mound research on all fronts. During this period surveys made on land being prepared for large-scale construction sites became an important means of discovering many previously unknown burnt mounds. Examples of these in Wales were work carried out along the route of the Rhosgoch to Stanlow Shell Oil pipeline (mostly in Anglesey) which yielded seven burnt mound sites (White 1977), and a watching brief during re-routing of part of the Cardigan-Aberystwyth trunk road, where four burnt mounds were found (Williams 1985). Also in Wales a number of other excavations were carried out, notably of two mounds at Carne, near Fishguard (James 1986) and one mound each at Felin Fulbrook (Williams *et al.* 1987) and at Graeanog (Kelly 1992).

In Scotland at the same period, J.W. Hedges (1975) published an extremely important report on his excavations of two complex burnt mound sites at Liddle and Beaquoy in Orkney, where the operational features were enclosed within stone buildings. In this report he also showed the distribution of known burnt mounds in Orkney and Shetland and compared it with the distribution of agricultural land, proving that burnt mounds could be found on land useful for farming, a point which had previously been disputed. He later produced an extensive report on a site on Burra Isle, Shetland, where another burnt mound had a building-enclosed hearth and trough, but which also included a nearby apparently domestic building and a field system (Hedges 1986). Other investigations in Scotland at this time included general surveys of Fair Isle, which uncovered several burnt mounds (Hunter 1984 and 1985) and a study of burnt mounds in Sutherland and Caithness (Blood 1989) which found that most were associated with human habitation.

In England between 1960 and 1990 the focal region for burnt mound research was the West Midlands, especially Birmingham and vicinity, and the most active researcher was M.A. Hodder. Inspired by explorations carried out in the area by M.J. Nixon (1980) locating at least seven burnt mounds, L.H. Barfield and Hodder (1981) excavated two of these mounds at Cob Lane in Birmingham, which led to additional surveys and excavations in the surrounding area (Burnett 1986 and 1987; Hewitt and Hodder 1988; Barfield and Hodder 1989; and Hodder and Welch 1990), resulting in a total of more than 50 known burnt mounds in this basically urban region.

Another area of special attention at this time was the New Forest, where two surveys together showed the presence of well over 20 burnt mounds (Pasmore and Pallister 1967; Pasmore 1984). The earlier article also included a report on a burnt mound excavation claimed as the first from south England. Later, another southern excavation was carried out in Swales Fen, Suffolk (Martin 1988).

In Ireland in the 1980s the series of Irish government-sponsored county surveys and inventories began to be published (Brindley 1986; Buckley 1986; Moore 1987), as well as two similar locally produced publications (Lacy *et al.* 1983; Cuppage *et al.* 1986), all of which contained listings of burnt mounds in their areas. Also in the 1980s there were several gas pipeline construction projects which together uncovered 25 fulachta fiadh, of which nine were fully excavated (Cleary *et al.*1987, 45-50; Gowen 1988, 125-35). Meanwhile, surveys located at least 120 fulachta fiadh in just one parish of Co. Mayo (Buckley and Lawless 1987; Buckley *et al.* 1988; Lawless 1990), 242 in the Burren area of Co. Clare (Coffee 1984), and 5 on Valencia Island (Mitchell 1989, 96-9). Excavations were carried out in Co. Cork (Hurley 1987a), Co. Kilkenny (Prendergast 1977), Co. Kerry (Ryan 1976) and Co. Tipperary (Buckley 1985). Fulachta fiadh research was clearly expanding to cover more of the country than just the southern area in and around Co. Cork, where these mounds had long been known and investigated.

The period from 1960 to 1990 was also a time of intermittent speculation about the function of burnt mounds. In an article chiefly dealing with allusions in Irish legends to washing and bathing, Lucas (1965) thought the weight of evidence was on the side of cooking as the principal use of fulachta fiadh. However, he believed they could also have been used for bathing, especially as the legends mention cases of therapeutic bath water prepared with meat and bones added as if making soup! He also suggested that fulachta fiadh could have had semi-industrial uses, such as the washing or dyeing of cloth in bulk, or the preparation of hides for making moulded leather products, such as shields (*ibid*, 79).

In an article which demonstrated that gold, copper, arsenic and tin are widespread in small amounts throughout Northern Ireland and Wales, C.S. Briggs (1976) argued that these metals were probably recovered by Bronze Age people from such now-unlikely sources as stream sediments. Quoting the previously-mentioned ideas of W. Davies (1810), he hypothesized that metal was processed from such ores at burnt mound sites. One year later R.B. White (1977), in his report on the Rhosgoch to Stanlow pipeline excavations mentioned earlier, referred to the seven burnt mounds discovered as "tentatively interpreted Bronze Age metal-working sites". In one of these he found a 1cc-size piece of slag. Sent to P. Northover for analysis, the slag was judged to have resulted from the smelting of chalcopyrite ore (*ibid*, 471-2). Furthermore, White quoted from a report of a smelting experiment in which H.H.

Coghlan (1940, 49-65) claimed to have succeeded in producing copper metal from carbonate copper ores in a pit without artificial draught by heating to a temperature of 700°C – 800°C with a pottery vessel placed over the ore (summarized in Coles 1979, 178). However, White's observations and ideas seem not to have been followed up by anyone later.

The function-related argument which caused the greatest stir among archaeologists at this time was the sauna theory put forward by Barfield and Hodder (1987). They based their opinion heavily on their own Cob Lane excavations where no bone was found, although their pH tests proved neutral, so bones from cooking should not have been destroyed by acid. They also cited ethnographic examples of sweat houses and steam baths, and reinterpreted some well-known excavations as saunas. They were answered the following year by D.A. O'Drisceoil (1988) who noted that the sauna idea was not new, Trench, Forsayeth and Lucas having mentioned it previously. He then traced the history of the cooking idea back to the old Irish legends supported by ethnographic evidence from various countries. He pointed out that bones were found in his own excavation in the Burren of Co. Clare, a limestone region, where the alkalinity of the environment would preserve them. Arguing that burnt mounds may have been used for both cooking, primarily, and steam-bathing, secondarily, O'Drisceoil noted several previous excavations where nearby huts, usually indicated by post holes, could have provided the required enclosed space for a steam bath, but such huts are found at only a small minority of burnt mound sites. He thought the presence of the trough was the strongest argument against bathing as the principal function of burnt mound sites, as it would be uncomfortable to sit in along with the hot stones, and would be unnecessary for supplying water to produce steam, since a stream was nearly always close at hand. Finally, O'Drisceoil urged that future excavations of burnt mounds should be undertaken in ways that directly address the question of function, advice unfortunately not very well followed.

The International Conferences

By the late 1980s a rather massive amount of uncoordinated data from burnt mound excavations and surveys was building up and was in need of overview and systemization. There was a growing sense that burnt mounds were an abundant, but undervalued, type of monument which might prove to be an especially helpful asset for understanding the Bronze Age in the British Isles, and therefore burnt mound research should be promoted. Also, since the function of burnt mound sites was still unclear, there was a need to generate new ideas and develop ways of testing theories. These concerns culminated in two international conferences held in 1988 and 1990 which produced probably the only two books ever wholly devoted to burnt mounds and related research.

The first of these volumes, *Burnt Offerings* (Buckley 1990a), provided summaries of research trends in Ireland, Scotland, and certain parts of England and Wales, through prefaces and other general articles. Also included were papers covering new excavations, some from areas where burnt mounds previously had been little explored. There were also some specialized articles, including a couple dealing with ethnography and Irish legends, but only two, on different rock types (Buckley 1990b) and soil analysis (Mate 1990), offered any promise of new testing methods which might help evaluate theories of function.

The title of the second volume, *Burnt Mounds and Hot Stone Technology* (Hodder and Barfield 1991), shows the attempt in the second conference to focus more on producing new ideas as to the purpose of burnt mounds. About half the papers in this collection had some relevance to the question of burnt mound use. Two of these covered ground already well trampled on the cooking vs. bathing debate (Barfield 1991a) and Irish literary references (Gillespie 1991). Others described ancient structures interpreted as ovens in Switzerland (Ramseyer 1991) and Canada (Campling 1991) which are somewhat similar to burnt mound sites of the British Isles. A review of a conference in France on prehistoric hearths suggested several tests which can be carried out to help determine function (Barfield 1991b). Another paper discussed the possibility that burnt mounds could have been used for fulling textiles (Jeffery 1991). M. Ehrenberg (1991) tried to correlate burnt mound locations with Bronze Age metalwork findspots. It is not very clear whether she was attempting to find evidence that burnt mounds were used for metallurgy, or simply that they were sited near settlements. In any case, the correlations seem not very close.

After the Conferences

The two conferences and the books resulting from them probably marked the high point of burnt mound research up to the present time. Since the conferences most research has continued along much the same lines and in the same forms as before. Excavations and surveys continue to expand in number and in territory covered, but most do not incorporate new testing techniques nor are they designed to work toward finding the answer to the question of function. In fact, there seems to be less interest now in the function of the mounds than in the years before the conferences. Perhaps there is a feeling that everything has already been said which can be said about function, and there is no alternative to leaving the matter an open question. Or perhaps most researchers are now thoroughly convinced that the matter has been settled.

Looking at what has been accomplished in recent years, the series of archaeological inventories of the counties of Ireland has continued apace, with at least half the country's territory now covered by them. Watching briefs on large construction projects are turning up an ever larger proportion of the burnt mounds both found and excavated. Urban redevelopment projects have joined pipeline and road construction as major sources of these newly-identified mounds.

One of the biggest thrusts of survey and excavation activity in recent years has been outward from Birmingham deep into virtually all the surrounding counties. The most concerted effort has been toward the northeast where burnt mounds have been found in Leicestershire (Ripper 1997; Coward and Ripper 1999; Clay 1999; Beamish 2003), Nottinghamshire (Garton 1993; Garton *et al.* 1997; Elliott and Knight 1998), and Derbyshire (Beamish and Ripper 2000; Beamish 2001). To the northwest of Birmingham, Leah *et al.* (1998) has recorded 20 burnt mounds and 28 burnt stone spreads (some possibly burnt mounds) in the wetlands of Shropshire and Staffordshire, and others have been excavated at Rodway in Telford (Hannaford 1999) and at Milwich in Staffordshire (Welch 1997). To the south of Birmingham, salvage operations, such as that carried out by Jackson and Napthan (1998, 57-68) in Worcestershire, turned up large amounts of burnt stone in pits with charcoal-flecked fills and Bronze Age contexts which could be remains of burnt mounds.

In the counties along the south coast of England, a field-walking survey identified six burnt mounds in the Avon Valley just west of Hampshire's New Forest where burnt mounds had long been known (Light *et al.* 1995, 73-5). To the west of that, in Bestwall, Dorset, a burnt mound in close proximity to a Middle Bronze Age house has been excavated (Ladle and Woodward 2003), and to the east of Hampshire, in West Sussex, fieldwalking discovered several dense concentrations of fire-cracked flint, suggesting the remains of burnt mounds, with a Late Bronze Age settlement nearby and a metalwork hoard found between (Dunkin 2001).

In Norfolk, where burnt mounds are often called "potboiler mounds", most are composed of flint and the features differ somewhat from elsewhere. They tend to have a series of small pits underneath, in addition to a trough-like larger one, and often date from the earliest "copper" Age (e.g., Crowson 1995). A recent burst of research activity has produced quite a lot of evidence of burnt mounds in Norfolk. A field-walking survey in the Wissey Embayment area carried out in the 1980s and 1990s by the Fenland Project (Hall and Coles 1994) identified more than 300 burnt flint sites. In northeast Norfolk near Aylsham eight potboiler concentrations were found along streams (Davison 1995). An enigmatic site near Norwich, excavated by Percival (2002), consisted of several pits, of which one large one contained a charcoal-rich material with 654 burnt flints and was dated to the Beaker period; it could possibly represent remains of a burnt mound.

A few burnt mounds have been located in the London area in recent years. A probable burnt mound was found in Kensington, close to the site of a Late Bronze Age metalwork hoard discovered in the 19th century (Moore *et al.* 2003). In Kingston-upon-Thames (Serjeantson *et al.* 1992) and at Runnymede (Needham 1991, 116) large quantities of burnt flint have been located in Bronze Age contexts, suggesting they were once burnt mounds. From an excavation at Harlow New Town, north of London in Essex, almost 60 kg of burnt flint were recovered and presumed to represent a burnt mound (Medleycott *et al.* 2000).

The north of England is another region recently opened up to burnt mound research. Two surveys of the Bolam and Shaftoe area of Northumberland, the first by J. Davies and J. Davidson (1989) and the second by Davies alone (1995), found two burnt mounds and another possible one. D. Cowley (1991) identified five more burnt mounds in an area northwest of Alnwick, two of which were later excavated by P. Topping (1998), proving to be classic examples. Another such excavation was carried out in Cumbria on the outskirts of Kendal (Heawood and Huckerby 2002). Most recently, T. Laurie (2003) has provided a gazetteer of the many known burnt mound sites (most located by himself) in the Yorkshire Dales and Teesdale.

A BAR volume wholly devoted to research on the Isle of Man contains an article listing 171 burnt mounds found by field-walkers there over several decades (Garrad 1999). This study follows the much earlier excavation of three burnt mounds on Man by Cubbon (1964 and 1974) and another carried out by a class of college students (Radcliffe 1996).

Meanwhile, in Scotland in the last few years burnt mounds have been found in the south in sizable numbers. A survey along a new gas pipeline in Dumfries and Galloway netted more than 50 sites with burnt mound features (Maynard 1993). Near Crawford in Clydesdale, Banks *et al.* (1999) has excavated two burnt mounds and summarizes information on two others in Annandale. The first burnt mound excavated in the Western Isles, in North Uist (Armit and Braby *et al.* 2002) was found to be a complex affair with three associated structures, rather reminiscent of some in the Northern Isles. The new technique of organic residue analysis to test for lipids was used in this excavation, but on a potsherd, not the mound material itself, and residual fat, probably from sheep, was found. The fuel residues here appear to have been heated in a poorly oxidizing environment, perhaps with stones buried in a pile of peat, the fuel used. Another somewhat similar burnt mound, one of a group of 14 found through a survey, with an associated "non-domestic" building, was excavated in Shetland at Tangwick (Moore and Wilson *et al.* 1999). The authors are among few in the current period to include some discussion of function. They also point out that a number of burnt mounds have produced mediaeval dates; however, it is uncertain how these dates should be interpreted.

In Wales recent investigations have turned up several burnt mounds in Snowdonia National Park (Fairburn 2001) and one has been excavated on its outskirts (Kelly 1992). Others have been excavated on Anglesey (Smith and Kenney 2002; Maynard *et al.*1999) and nearby on the mainland (Davidson 1998).

The Question of Function

The history of burnt mound research shows that a variety of ideas have been suggested as to the function of these sites, but none have so far been accepted definitively. Cooking and bathing are the most generally accepted theories for several reasons: 1) they have been shown experimentally to be possible at reconstructions of burnt mound sites (e.g., Layard 1922, Bullows 1927, and O'Kelly 1954, mentioned above); 2) they are supported by references in Irish legends and early literature (e.g., Lucas 1965); and 3) ethnographic examples from other parts of the world demonstrate that other peoples have used somewhat similar sites for these purposes (e.g., Barfield and Hodder (1987), O'Drisceoil 1988). However, the Irish legend basis, the original reason for the assumption that burnt mounds were cooking or bathing places, can be questioned. Nearly all dated burnt mounds are now known to date to the Bronze Age, which ended around 800BC, and it was well over a thousand years later before any such legends could have been written down. That is a very long time for legends to have remained intact and factual through oral tradition alone. For example, Finkelstein and Silberman's comparison of archaeological evidence with history according to the Hebrew Bible (2001) suggests that oral tradition only maintains some historical accuracy up to about 200 years after the event. What is more likely is that the Irish legends concerning burnt mounds arose at a time quite a few centuries after burnt mounds went out of use, when their actual purpose had been forgotten, but while they were still prominent and common features of the landscape. This condition would invite people with imagination to invent stories which offered explanations for these enigmatic protuberances widely seen. It must have been with some such thoughts in mind that Brindley and Lanting, in their contribution to the first international conference on burnt mounds, said, "fulachta fiadh date to the Bronze Age" and "have no connection with descriptions in Early Historic and later texts to practices involving cooking with stones. ...There is, therefore no evidence or even compelling argument to indicate that fulachta fiadh are primarily cooking sites, although their widespread distribution and apparently fairly regular use might support such a function" (Brindley and Lanting 1990, 56). What they wrote applies equally to the bathing theory. In support of these explanations, nevertheless, there remain the facts that cooking and bathing would both have been possible at burnt mound sites, and are activities known to have been carried out elsewhere under similar circumstances.

Cooking and bathing are basically domestic functions, which raises another problem because most burnt mounds are not near known settlements of their period. Normally, habitation places would be expected to be the locations of domestic activity. Most other theories of possible burnt mound site uses are industrial. These include metal processing (Davies 1810, White 1977, and possibly Ehrenberg 1991), boat-building (Parfitt 2006), leather-tanning, or cloth-washing or dyeing (Lucas 1965), textile-fulling (Jeffery 1991) and beer-brewing (Gustawsson 1949). None, it seems, has been investigated to any very significant extent.

The research described in this paper aims to explore one suggested industrial use, metal processing, attempting to discover whether there is a relationship between it and burnt mound sites. A major reason for choosing metal processing is the date-range correspondence in the British Isles between burnt mounds and the Bronze Age, which, including its beginning "copper" phase, is the earliest metal-producing period. Assuming that the earliest metal-making sites would be the simplest, there seems a possibility that they might have been burnt mound sites, since burnt mound sites, on the whole, have quite simple features. When copper was replaced, for many uses, by iron, a metal more difficult to smelt, it seems likely that metal production sites would have required more complex features than those at typical burnt mound sites. Therefore, from that time onward, burnt mounds would no longer have been produced, if they had been copper processing sites. Thus this hypothesis accounts for the similar date ranges between burnt mounds and the period when copper was the principal metal in use. In order to investigate its validity, early copper production methods and burnt mound site characteristics became the twin foci of this research.

Plan of Research

The research program was planned as a six-stage project, designed to test the possibility of a relationship between burnt mounds and early copper production in three different ways. Before these tests could be conducted, it was essential to gain a wide knowledge of both subjects of interest. A decision was made to limit the geographical scope of the project to the British Isles, although burnt mounds are also found in Scandinavia. The six stages which have been followed are:

1. A literature search for known burnt mound sites, including both excavated sites and mounds found through surveys. Some of the results of this search are found in the historical section of this chapter.
2. A literature search for Bronze Age copper processing sites to gain an understanding of how such processes worked. Because very few such sites are known in the British Isles, it was necessary to extend this search to the Near East and other parts of Europe, as well as a few sites in other parts of the world. Chapter 2 is a result of this search.
3. A study of burnt mound characteristics. A detailed study was made of a representative sample of excavated burnt mound sites in order to judge whether, in view of what is known about early copper-processing sites, the burnt mound characteristics fit the requirements for that function. (Chapter 3)

4. A geochemical study. Analyses were carried out on samples of mound material from three burnt mounds, determining concentrations of various, mostly metallic, elements. It was hoped that copper concentrations, in particular, would provide evidence for or against the possibility that the sites had been used to process copper. (Chapter 4)
5. A geographical comparison. Maps were prepared showing burnt mound and copper source locations throughout the British Isles, then compared to judge whether the two types of sites were geographically related. (Chapter 5)
6. Conclusions and proposals for further research. It is hoped that this project may lead to more studies, both of the copper processing possibility and of other possible burnt mound functions. (Chapter 6)

Chapter 2

BRONZE AGE COPPER PRODUCTION

A Brief Chronology of the Earliest Copper Production

Native copper (that found in nature already in the metal state) was used to make beads and small instruments in the Near East as long ago as the 8th/7th millennia BC (Hauptmann 2003, 90). Native copper was often found together with some of its colourful (and thus easily identifiable) minerals, which were used for such purposes as pigments and ornaments at about the same period. Some kind of identity between copper and its minerals may have been recognized by the green colour which they imparted to a flame, and by the green deposit which formed when the metal was left in a wet environment. Native copper was probably worked into objects by hammering and then annealing at high temperature. When people were able to build fires which could heat to temperatures above the melting point of copper (1083° C), there was no technical barrier to producing copper from its compounds, as it would form from them under appropriate reducing conditions, at similar temperatures (Craddock 1995, 122). Smelting was definitely established in the eastern Mediterranean area by the first half of the 4th millennium BC, and there is some evidence that it may have begun as early as the 6th/5th millennia BC in the Taurus – Zagros mountain belt of the northern Near East, where copper ore deposits were available (Hauptmann 2003, 91). In the British Isles copper began to be produced around the mid-3rd millennium BC, possibly at the recently-discovered site at Ross Island in Ireland, which has been dated to c.2400-1900 BC (O'Brien 2004, 155).

Copper Minerals

Copper-bearing ores can be divided into two groups which are somewhat differently treated in conventional smelting methods. The oxide/carbonate group, which can be smelted without preliminary roasting, includes those minerals usually found on or near the rock surface, where they have undergone oxidation. Some of those most often found are malachite ($CuCO_3{\cdot}Cu(OH)_2$) – bright green, azurite ($2CuCO_3{\cdot}Cu(OH)_2$) – bright blue, and cuprite (Cu_2O) – red-brown. The sulphide ores normally require roasting before smelting and are usually found deeper inside the rock structure or where the top oxidized layer (called gossan) has been removed (for example, by glacial action). The most abundant and important of these sulphides for copper production is chalcopyrite ($CuFeS_2$), usually gold coloured and metallic in appearance. Others in this group include chalcocite (Cu_2S) – grey and metallic, bornite (Cu_2FeS_4) – peacock blue and iridescent, and covellite (CuS) – deep blue (Charles 1994, 66-7). It is easy to see why the copper minerals attracted attention so early!

The earliest copper metal made in the British Isles contained an unusually high amount of arsenic impurity, which probably was accidental, but significantly improved the quality of the metal. In this case the copper ore which had been smelted most likely contained tennantite (Cu_3AsS_4), a sulphide, and/or one or more of its oxide derivatives formed by weathering, the copper arsenates ($Cu_3As_2O_8\, n{\cdot}Cu\, (OH)_2$) where n is a variable additional element. The sulphidic ores would have produced sulphur dioxide (SO_2), which has a pungent, cough-inducing odour, when heated. Arsenic-containing minerals create a garlic odour when heated. These properties might have helped Early Bronze Age people classify the copper minerals in different ways for special treatments (*ibid*).

Bronze Age Copper Mining in the British Isles

Once there was a basic understanding of how metal could be obtained from copper minerals, and some such mineral sources had been identified, the next step would have been the extracting of mineral-rich ore in some quantity from the rock masses in which it was embedded; i.e., mining. Only in the past quarter-century has there been confirmation of the existence in the British Isles of copper mines dating to the Bronze Age. The earliest such mine workings, from the Neolithic-to-Bronze Age transition period, are at Ross Island in Ireland, as mentioned above. At Mt. Gabriel and its surroundings, also in Ireland, over 30 mines have been found dating to about 1700-1500 BC (O'Brien 1994, 51). In central Wales at Cwmystwyth, and at several nearby sites, there are mines dating from approximately the same period. In north Wales the Parys Mountain mine complex was worked perhaps a century or two earlier, and at Great Orme mining activities were carried on from the Early Bronze Age to the Early Iron Age, a period of about a thousand years! In western England, rather close to Wales, the Alderley Edge and Ecton mines were in operation in the Early Bronze Age (Timberlake 2003, 26-7).

Some of these mines were opencast (surface workings only), but Parys Mountain and Great Orme were complexes of several intersecting underground tunnels. At all the sites, Bronze Age activity was first suspected through finds within the mines of stone hammers and charcoal remains of fires set to make the ore easier to remove. By now many radiocarbon dates have been obtained which put the dating beyond doubt. A surprising aspect, however, is that, with the probable exceptions of Ross Island (O'Brien 2004, 223-61) and Great Orme (Chapman 1997, 56-7), no evidence of smelting has been found in the immediate vicinity of these mines, and even sites where ore may have been prepared for smelting have only been found near the same two sites (*ibid*), plus Mt. Gabriel (O'Brien 1994, 106-13). Therefore, to investigate these aspects of the making of Bronze Age copper, it is necessary to turn to sites outside the British Isles for much of the information.

The Pre-Smelting Treatment of Ore

Once the ore-bearing rock had been extracted by mining, the next step in the processing of copper was breaking the mined rock into smaller pieces, discarding those bits which showed no signs of containing desired minerals. This is sometimes called ore-dressing, and normally was carried out either inside mines or immediately outside, the discarded pieces forming a spoil heap. Following this first rough concentration of the ore, the processing could be continued in the mine vicinity, or the slightly concentrated pieces could be transported to some other location selected for reasons other than closeness to the source of the ore. The next operation would have been further concentration of the ore by successively crushing it into smaller and smaller bits, followed each time by hand-sorting. This very labour-intensive process is called beneficiation, and seems to have been accomplished using hand-held pounders or hammerstones on flat rocks or sometimes querns, and for very fine crushing, mortar-like depressions in rock surfaces (Craddock 1995, 156-62). By the end of this procedure the concentrated ore particles seem generally to have been crushed to somewhere between the size of a bean and a grain of sand.

The separation of the ground ore from waste material (gangue) usually would have been assisted by washing with water in any of several ways, making use of the greater heaviness of metal as compared with the materials with which it is combined to bring about the separation (*ibid*, 163-6).

According to conventional smelting requirements, when the ore contained sulphidic minerals, it would have been necessary to roast it in the open air to replace the sulphur in it with oxygen before smelting. This could have been done either after beneficiation or at some point during the process, with further beneficiation following the roasting. The purpose of roasting was to facilitate smelting and eliminate sulphur as an impurity in the resulting metal (*ibid*, 167-9).

<u>Examples of Beneficiation and Roasting</u>

At Timna, in the Arabah region of Israel, it is possible to track ore from the place where it was mined in the Chalcolithic period (4^{th} millennium BC) on the side of a mountain, to an "ore-dressing station" at the foot of the mountain at least 1 km. from the mine, from where it was apparently transported about 2 km. to what the excavator has interpreted as a "working camp" (Site 39A), which presumably prepared the charges for a smelter (Site 39B) on a hill just above. The working camp was located quite close to the Wadi Arabah (which may at times have provided water). The camp was a circular area, partially enclosed by a series of small "working installations" and fireplaces arranged around a large courtyard which contained a couple of possible hut structures, perhaps temporary dwellings for the workers. These features, plus hammerstones and mortars and a quantity of copper ore nodules convinced the excavators that the place had been used for such pre-smelting activities as beneficiation and roasting. Pottery sherds and flint implements found at Sites 39A and 39B were of the same types, suggesting the two sites were closely linked (Rothenberg *et al.* 1978, 4-7).

Turning to the British Isles, O'Brien excavated areas adjacent to the Bronze Age copper mines at both Mt. Gabriel and Ross Island, and interpreted them as working places for the processing of the mining output. At Mt. Gabriel there was a spoil heap, in which many broken stone mauls were found, outside the mine entrance, and on which O'Brien thought workers had carried out the initial ore dressing. Between that and a stream to the south were two or three flat stone arrangements where crushing of the ore could have been carried out, with two associated broken stone maul concentrations. The largest of the flat stones was surrounded by green mineralized broken rocks and a sticky sediment. Between these possible work sites and the spoil heap was a large (0.9x1.38x0.7m) trough, apparently designed to hold water, as it filled with water automatically when emptied, but of unknown purpose. Just south of the trough, a line of four post-holes led away from the trough, and were thought by O'Brien to indicate some kind of temporary shelter. There was no hearth or other sort of roasting facility, but as the ore being mined was principally malachite, roasting would not have been necessary (O'Brien 1994, 93-116).

O'Brien also excavated the early mining and ore processing site at Ross Island in County Kerry, Ireland, dating to about 2400 – 1900BC. The ore processing area there from Period 2A was located close to a lake shore, as well as to the ancient mine which was its copper source, and contained features including two "silt basins", irregular hollows which may have been used for ore washing; and ten "furnace pits" (some definite and some possible) which showed signs of intense burning around the edges, but not within the pits, and most of which seemed likely to have been roasting places. These pits tended to be sub-circular, but rather irregularly shaped, and on average around 1m in diameter and 0.5m deep. However, two of these were considered to have been possible smelting places and were labelled "furnaces" because each appeared to have had a stone structure which could have helped supply forced air to the fire inside the pit. In one of these furnaces there were three large stones forming a U-shape in the pit, and it was thought that air could have been directed at the opening of the U by blowpipe or bellows to increase the heat of the fire. Beside the other furnace there were three stones together, thought possibly to have formed a bellows support. No crucibles or moulds were found, and very little slag, although supplies of pure quartz sand (which could have been added to a smelting mixture as a flux, and if so, might have produced slag) were found, so it is not certain that smelting was carried out there (O'Brien 2004, 168-267, 466-72).

At Mühlbach on the Mitterberg in Austria, a quite elaborate apparent roasting site was found. It was part of a complex late Bronze Age smelting site, located on a mountainside. Herdits (2003, 69) writes of its location: "Its position by a stream is typical for Bronze Age smelting sites in the eastern Alps; water was obviously needed for the beneficiation of the ore". The roasting bed was on a terrace slightly above the smelting furnaces. In its first phase it was a long (more than 2m), irregular, shallow pit coated with red-burnt clay and surrounded by upright stones, perhaps to fence in the roasting ore. Broken slag cakes were scattered on the surface, possibly to increase air flow. In a second phase the old bed was covered with clay, earth, and old slag, and a smaller (1m. long) bed built beyond one end of the old one, also with a red-burnt clay floor and surrounding stones. Next to the roasting bed was a pit (probably deeper than the bed, but no figures given), also with burnt clay walls and containing many stones. The use of the pit is uncertain, but the author suggests it might have been a water pit for cooling roasting products, hot metal or hot slag. Postholes indicate a possible roof covering the whole installation (*ibid*, 70, 74).

Roger Doonan (1994), who had worked on Bronze Age smelting sites in the eastern Alps, carried out experiments aiming to recreate beneficiation and roasting techniques which may have been used there, with interesting results. From an Austrian mine he acquired 150kg of ore, which contained mainly chalcopyrite and some associated oxidic minerals plus gangue (other, unwanted material) consisting principally of limonite ($2Fe_2O_3{\cdot}3H_2O$). He also obtained 50kg of haematite (Fe_2O_3), although it is not entirely clear how or why this was used. (Haematite, he states, is an excellent flux, but for roasting presumably a flux would not be necessary, and in the experiment descriptions there is no indication that it was used.) He found the best method of crushing the ore was with a hand stone (a beach pebble) on a saddle quern-shaped stone. It required 19 man-hours to crush the ore and the haematite to the point where they would pass through a 1 cm screen. Fourteen kg of gangue was sorted out while crushing. Hand-sorting the remaining 136 kg of crushed ore into 5 grades from high-grade to useless took 42 man-hours. Dust from the crushed red-brown limonite covered everything, making sorting extremely difficult, so a procedure of continually washing the nodules in running water was adopted, which made recognition of minerals in the wet nodules even easier than in dry, dustless ones. Doonan thinks this may be why smelting sites in the eastern Alps were always built by a stream. At the end of sorting he had 33.4 kg of high-grade ore.

Following the beneficiation, 3 roasting experiments were conducted in a roasting bed built to have somewhat similar dimensions to the one described above at Mühlbach (0.9x2x0.2m), but without the clay lining. Each of the 3 experiments had slightly different roasting conditions: 1) fire built on the roasting bed floor, 2) fire built on a stage elevated to ground level, and 3) same as 2), except planks of wood laid around the edges of the fuel stack to limit air drawn in from below. The same amounts of ore and fuel were used in all experiments, but were somewhat differently arranged. The maximum temperatures recorded in the three experiments were 782°C, 892°C, and 847°C, respectively. However, the third experiment continued burning longer (1 ½ hrs, instead of 1 hr) and was the most successful in terms of the degree of oxide penetration in the nodules. Some "atypical" products appeared in small amounts: magnetite (Fe_3O_4) and fayalite (Fe_2SiO_4) slag, and prills and stringers of copper metal (formed only inside the nodules); these are products more to be expected from smelting. This result shows, to a very limited extent, a merging of the processes of roasting (with oxidizing conditions intended) and smelting (normally carried out in reducing conditions). However, reducing conditions may have occurred inside the nodules, where the outer portion covered the inner, and the reaction might have been helped by the flux, if indeed it was used. Doonan (1994, 88) lists several equations to describe reactions which may have been occurring, more or less simultaneously, in this complex roasting-smelting mixture:

1. $CuFeS_2 + 3O_2 \rightarrow FeO + CuO + 2SO_2$
2. $6CuFeS_2 + 19O_2 \rightarrow 2Fe_3O_4 + 6CuO + 12\ SO_2$
3. $4CuFeS_2 + 13O_2 \rightarrow 2Fe_2O_3 + 4CuO + 8SO_2$
4. $2FeO + SiO_2 \rightarrow Fe_2SiO_4$ (fayalite)
5. $4CuFeS_2 + 7O_2 \rightarrow 4CuS + 2Fe_2O_3 + 4SO_2$
6. $CuFeS_2 + 4O_2 \rightarrow CuSO_4 + FeSO_4$
7. $5CuO + CuFeS_2 \rightarrow 6Cu + FeO + 2SO_2$

Of the first three equations, representing different ways that chalcopyrite may be oxidizing in the roasting process, the first reaction is the preferred one as it gets rid of the sulphur and produces cupric oxide, the desired intermediate product on the way to forming copper metal, and also ferrous oxide, which, as shown in the 4th equation, reacts with silica (from remains of the gangue, or often added as a flux) to become fayalite, the most favoured form of slag. The following two equations show still more ways that chalcopyrite may react with oxygen to form additional unwanted products, and the final equation illustrates how an oxide and a sulphide of copper might smelt together to form copper metal. These equations emphasize the importance of carefully controlling conditions, in both roasting and smelting, to maximize production of desired products, and minimize that of less desirable ones.

Finally, after each roast "fuel ash and charcoal were separated from the ore by sieving in a tank of water. The charcoal floated which allowed it to be skimmed off whilst the ore remained in the immersed sieve" (Doonan 1994, 93).

Conventional Smelting

Smelting is basically the extraction of a metal from its compounds found in nature by means of chemical reactions involving the reduction of the combined form of the metal. The reactions which take place in the making of copper are a complex series and vary with varying mixtures of different copper minerals, as has been illustrated, to some extent, in the set of equations above. A flux of either iron oxides or quartz is usually added to balance the amounts of iron and silica in the ore, in order to produce fayalite (Fe_2SiO_4), the most desirable component of a resulting slag. Smelting eventually developed into essentially the same system virtually everywhere, which is still in use today. In general, this happened quite early in the course of the production of metal, and certainly by the time iron began to be made in any area, and in some cases even during the Early Bronze Age. A major principle on which this technology is based is the conversion of almost everything involved in the reaction (ore, flux, and reaction products) to liquid form, which inevitably requires quite a high temperature. The forming heavy metal droplets can then fall through the liquefied remaining materials (i.e., slag), then join to become a mass of molten metal, which can be removed through a tap at the bottom (after which the slag can be removed in the same way). With this system more reactants and fuel can be added periodically so that the process can be continued for a relatively long period. A higher proportion of the ore minerals are reduced to metal and greater efficiency of fuel is obtained than would be the case without a tapping mechanism, which would mean a shorter heating period. With a tap, one preheating will suffice for the production of much more metal. To produce these conditions, however, there are a number of requirements. A shaft furnace is needed, essentially a sturdy container of some height, usually cylindrical, with a fire-resistant lining and a tap at the bottom. A temperature must be maintained in the furnace above the melting point of the metal to be produced as well as that of the slag. In order to produce such a high temperature, bellows, or other means, must direct air blasts at the fire, while at the same time the furnace structure and the competing gases being formed in the reactions serve to restrict the flow of oxygen to the ore being reduced. The bellows require fire-resistant tubes, called tuyeres, inserted into the furnace at appropriate points to serve as intermediaries between the hot interior of the furnace and the non-fire-resistant bellows. In early times, eventually the lining of the furnace deteriorated under these rather extreme conditions, and the process had to be stopped, so that the furnace could be relined or completely reconstructed (Craddock 1995, 169-74 and 180-9).

Clearly, this method of making metal is not a simple process, with so many factors to balance appropriately with respect to each other, and it seems remarkable that about five millennia ago, in the Near East, people were able both to conceptualize it and to make it work, without the benefit of modern scientific knowledge. It must have required a great deal of trial and error to work up to this point and get all aspects of it right. Some of the remains from simpler processes developed along the way to the final solution have come to light in various parts of the world. A few examples of these sites will illustrate the types of partial solutions to the problem of making copper which were tried in the Bronze Age.

Examples of Early Smelting Technologies

Of the two possible smelting sites so far discovered in the British Isles, the "furnaces" at Ross Island's 2A ore processing area have already been mentioned above. The other possibility, at Great Orme, is located about 1km from the mining area, and about 500m from the nearer of at least two wells or springs thought to have been ore washing places. Upon excavation, the feature most likely to have been a smelting place was a small V-shaped pit, which was first identified due to copper working debris eroding out of it, including shells, bones, crushed malachite, small fragments of copper metal, and "potboilers" – another name for the sort of burnt stones found in a burnt mound. Charcoal fragments removed from the dark silt fill of this pit have produced a radiocarbon date of 1580BC. Fragments of "a fine grained, weakly cemented, sediment matrix with one surface coated with a thin grey/dark grey curved vitreous skin" were also found in this context, and were thought perhaps to be the remains of a crucible or slag spill. Almost a hundred small pieces of copper-rich debris were recovered from the site, including crushed malachite, dolomite and slag, the last of which was found to have been derived from sulphide ores. The situation is complicated by a hearth nearby which has been radiocarbon-dated to 1220AD (Chapman 1997, 56-7 and Website 1).

At Feinan, now in Jordan, copper ore was being mined in the Chalcolithic period during the mid-4th millennium BC. About 2 km from the nearest mine the remains of a village labelled Wadi Fidan 4 have been excavated. It is located on a plateau about 20 m above today's bottom of Wadi Fidan, near the confluence of several wadis where water can be found all year round. In addition to mining tools found at this site, there were masses of small pieces of minerals and slags and fragments of crucibles (Weisberger 2003, 81). The crucibles, almost flat and about 11-14 cm in diameter, had been heated from above, and probably blowpipes had been used, as no tuyeres were found (Hauptmann 2003, 92). More recently, an excavation at Wadi Madsus nearby has revealed simple open hearths apparently used for smelting.

Vitreous material recovered from crucibles at this site show that the ore being smelted had never become fully molten and the "slag" was largely composed of partly decomposed ore and gangue. The principal constituent was delafossite ($CuFeO_2$), and iron silicates, magnetite (Fe_3O_4) and chalcocite (Cu_2S) were also present. This suggests that the process had been too poorly reducing even to take much of the iron present to its lower valence of +2, let alone to metallic iron. This meant that the most usual slag ingredient, fayalite (Fe_2SiO_4) could not form. The presence of chalcocite shows that sulphidic ore was at least part of the smelting mix. Two other contemporary settlement sites which were excavated also showed signs of a similar smelting process, and copper axes found at one of them were made of very pure copper with only a trace of iron in it (Craddock 1995, 128-9).

However, also in the Feinan area, "ovens", dated to the beginning of the early Bronze Age (EBAI), were found with circular bottoms which were quite similar to the Chalcolithic open hearths, but also with remains of clay sides which probably originally reached about 40 cm in height and had been remade several times. These ovens apparently had had at least partially open fronts, and were sited just below the crests of steep ridges, oriented into the prevailing wind. No tuyeres were found, and it is assumed that this careful siting was designed to make use of the wind in place of either blowpipes or bellows. A large number of small clay bars were found, some vitrified on one side and slagged. It is thought they may have formed a grill across the open fronts of the rudimentary furnaces or supported a partial front wall. The slags, mainly calcium oxide, manganese oxide, and silica, have a high manganese content and appear to have been produced with a partial oxygen pressure (pO_2) of 10^{-5} -10^{-10}, higher than the 10^{-12} of conventional smelting. The copper content remaining in the slag was about 3%, approximately an order of magnitude higher than that found in fayalitic slags, which this is not (Craddock 1995, 129-30). It is clear from the chemical composition of the slags from the two types of smelting places at Feinan that the Chalcolithic open hearth operations made use of sulphidic ore extracted from nearby mines where it was found in Massive Brown Sandstone, while the EBAI furnaces had used oxidic ores from different mines, also in the area, where the surrounding rock was Dolomite Limestone Shale (Hauptmann 2003, 95).

In southeastern Spain and Portugal there are several sites, dating from the Chalcolithic period (mid-3rd millennium BC), which bear a close resemblance to the Feinan Chalcolithic smelting sites, although they were in use about 1000 years later!

Craddock (1995, 144) assumes the technology must have developed there independently due to the great chronological difference. Again it was a simple, virtually non-slagging and poorly reducing process carried out in large open crucibles with no tuyeres found. At a site at Los Millares a 1m-diameter hearth with a clay annulus was found in a room where there was a scatter of malachite and small prills of copper. Large coarse open dishes, scattered on the floor, had been heated on the upper sides only, which were vitrified and slagged. The slag composition was similar to that from the Feinan Chalcolithic sites, featuring delafossite as a major component, which suggests a pO_2 of about 10^{-6}; i.e., not very reducing. The copper prills present were virtually free of iron. The penetration of vitrification on the dishes indicates about two hours of heating at high temperature. The only important difference from the situation at the Feinan Chalcolithic site was that the copper prills were rich in arsenic, probably due to a high arsenic content in the ore used, arsenic being a relatively volatile element. At another Spanish Chalcolithic site, Almizaraque, copper smelting furnaces, with bases like large crucibles, and several kinds of copper minerals (malachite, azurite, copper sulphate, cuprite, and copper arsenates – no sulphides) were found. Many fragments of these minerals had been partially reduced, suggesting either a pre-smelting roast or a poorly-reducing smelt. Also present were fragments of "basins", vitrified and slagged only on the upper side. The arsenic content of the ores was compared with that of copper artefacts found on the site, which showed that the arsenic had come through the smelting process into the copper (Craddock 1995, 132-4).

Other places where there is evidence that this "crucible" method of copper smelting may have occurred are sites at Buhen, Egypt (*ibid*, 130-1) and in the Balkans (*ibid*, 142).

At Timna, a Chalcolithic smelting site (39B) was located near the top of a hill just above site 39A (already described as an ore-preparation site). At the site there was a concentration of small fragments of viscous, porous and greenish slag. (Rothenberg *et al.* 1978, 4) (The colour and condition would seem to suggest that the process which produced it had been poorly reducing.) Upon excavation a bowl-shaped furnace, 45 cm. in diameter and 45-50 cm. deep, was found with a large stone block, brought from elsewhere, behind it. The furnace had no mortar lining, but many charred and slagged pieces of "imported" sandstone were interpreted as the refractory material used, thought to have risen to a height of about 80 cm. No tuyeres or bellows fragments were found, but Rothenberg believed that the furnace could not have been wind-blown, due to its depth and the prevailing direction of the wind (*ibid*, 7). However, it is difficult to think of another reason why this furnace was built up a hill and thus removed from its ore preparation area. Also, Craddock has conducted experiments which have shown that the wind direction changes just below the crest of a hill from what it is both above and below (Craddock 1995, 129-30). Rothenberg's belief that bellows must have been used is perhaps now open to question. The ore seems to have been a complex mixture of oxide/carbonates and sulphides, with malachite predominating. Due to the high iron content of the slag, Rothenberg thought an iron oxide flux must have been added, and believed it was derived from fossilized trees. As the furnace had no tapping mechanism, the slag contained much entrapped copper. A temperature reached of 1180°-1350°C was estimated from the melting range of the slag. (Rothenberg *et al.* 1978, 8-9) This furnace, though dating from the Chalcolithic, would seem to have more in common with the EBAI furnace at Feinan than with the Chalcolithic one there.

There are other, more complex, copper smelting furnace remains, dating from later periods, in the Timna area. However, when Tylecote and Boydell (1978) attempted to replicate for experimental purposes both the 39B furnace and another, Site 2, with more conventional features which dated to the Early Iron Age, only the simpler, older type, the 39B replica, could be made to produce copper effectively.

At the Middle Bronze Age Mühlbach smelting site in the Mitterberg area of the Austrian Alps a series of pairs of 8 furnace remains have been excavated, representing 4 distinct phases of use. They were built into a bank which is part of a steep slope, with a terrace containing the roasting area (previously mentioned) above and an apparent working platform on another terrace below. Beneath the lower terrace was a multiphased slag heap, with layers of slag and charcoal alternating with layers of debris from the destruction of old furnaces (including burnt stones and burnt clay) and the building of new ones. Some of the slag had been ground to a "sand" consistency and was found to have been used as a filler in pottery and clay from all phases. The furnaces had walls surrounding the back and sides of a central rectangular hearth, with the front apparently left at least partially open. One furnace in each pair was equipped with a specially constructed floor, consisting of stone slabs, slag cakes, wood and a clay covering; the other member of the pair had none of this (Herdits 2003). Sulphidic ores were smelted here, and the original excavators interpreted the process carried out as matte smelting; i.e., the formation of an intermediate product called "matte", which then requires additional roasting and resmelting to produce copper metal. However, subsequent analysis of the slags has suggested a very different process in which the ore may have been smelted directly to copper without even an intermediate oxide stage. The analysis showed that the slags were produced under poorly reducing conditions with a pO_2 of 10^{-7}, comparable to that at the EBAI site at Feinan more than a thousand years earlier (Craddock 1995, 142-3). If this is the case, though, it is hard to see why the process at Mühlbach appears so complex, with pairs of furnaces, an elaborate roasting facility, and fine crushing of slag (usually considered a useless by-product), all of which would seemingly better fit a matte smelting explanation.

While the above examples show a variety of early smelting techniques, and each is unique in some respects, they can be divided into two general groups which might be labelled "earliest" and "intermediate" (or "crucible" and "furnace"), based on the Chalcolithic and EBAI sites at Feinan, respectively. The earliest type is characterized by open hearths with little or no obvious superstructure, the use of large almost flat crucibles to contain the smelting mixture, and very little slag. The intermediate type has rudimentary shaft furnaces with at least partially open fronts, located near the tops of hillsides to make use of wind to provide air blasts. At both types of sites no tuyeres are found, and the slag has been produced in poorly reducing conditions and contains little or no fayalite.

Craddock's Further Investigations

In addition to noting the characteristics of many widely-distributed Bronze Age smelting sites, Craddock (*ibid*, 137-41) studied analyses of large numbers of copper and bronze artefacts produced in the Bronze Age. Iron metal is soluble in molten copper, so if reducing conditions in copper smelting were good enough to reduce some of the iron present in compound form in the ore and flux, then the amount of iron impurity in the resultant copper would be significant, probably more than 1%. If that copper were then remelted (i.e., refined), the iron would rise to the top of the molten copper and oxidize on exposure to the air. The resultant iron oxide could then be skimmed off with a stick. Copper refined in this way typically has an iron content of 0.1-1%. It could be further refined by a second remelting, but this is unlikely to be done since the quality of the copper would not be further improved by greater purity. Therefore, Bronze Age objects produced from copper smelted by methods that were essentially the now-conventional technique could be expected to have iron content greater than 0.1%. However, Bronze Age objects made from copper smelted by poorly reducing early methods would contain almost no iron impurity, since the iron compounds present in the smelting mix would not have reduced to metallic iron at all. Such artefacts could be expected to have iron content less than 0.1%. Recognition of this difference provided a way to test any early copper or bronze object to determine whether the copper in it had been made by a poorly-reducing or highly-reducing method. By using this yardstick, Craddock found evidence that essentially all the Bronze Age copper and copper alloys made in western Europe, including the British Isles, right through to the start of the Iron Age, have the low iron content expected from poorly-reducing processes, except those from Sardinia and Phoenician settlements in Spain. As a check on this conclusion, I looked up Coghlan and Case (1957) and noted the iron content of the 98 pieces of European Early Bronze Age copper and bronze items they had analyzed; 93 of the 98 pieces had the low iron content expected from poorly-reducing processes. The five that did not were all in Group II, classified as the "catch-all" category of unusual impurity profiles and thus of more uncertain provenance. Coghlan and Case had noted the unusually low iron percentages, but had attributed them to repeated refinings.

Craddock's Theory of Bronze Age Copper Smelting

Looking at data, such as those just recounted, from several parts of the world, Craddock (1995, Chapter 4) concluded that in many places the earliest form of smelting developed was a poorly reducing, little slagging technique. No telltale large slag heaps were left by such processes and often little or nothing in terms of structural remains, and what slag was produced had a different composition from that normally expected, so such sites would be difficult to identify and easy to overlook entirely. In some places, such as the Near East, this simple method relatively quickly evolved through intermediate stages to essentially the conventional technology used today. In other places, such as Western Europe, where even the simplest process may have been initiated up to 1000 years later than in the Near East, the earliest forms, or intermediate developments from them that remained poorly reducing, continued through the Bronze Age. In the British Isles, Craddock suspects that the simplest method alone, or with only minor modifications, continued in use through the Bronze

Age, which is the reason almost no Bronze Age smelting sites have yet been found in this region (Craddock 1990).

Craddock (1995, 135-7) mentions several experiments, usually successful in producing copper, to recreate the conditions of the simple early smelting process he has postulated. All of them use charcoal as the fuel with which the ore is covered in a crucible-like arrangement, and perhaps a question could be raised as to whether charcoal was being produced in the Early Bronze Age in the quantities needed, but given the more than a millennium of experience with pyrotechnology in the making of pottery by that time, this is probably a justified assumption. Otherwise, remaining charcoal could have been collected from places where ordinary fires had been made (Harding 2000, 217). In these experiments the temperatures reached seem to have varied within the range of about 900°C-1250°C. Smelting high-grade malachite appears to present no problem, but in the Bronze Age the ore would have required very careful beneficiation to reach a similar level of purity. In several experiments even sulphidic ores were smelted successfully under very moderate reducing conditions. For example, Rostoker *et al.* (1989, 11-25) smelted samples of ore composed of 71% chalcopyrite, 17% pyrite (FeS_2), and 10% silica gangue, by first roasting an appropriately-sized portion of each sample at 700°C, then mixing that with the unroasted remainder, covering the mixture with charcoal in a crucible, and heating to 1250°C. The equations which he believes describe the reactions taking place during the smelting phase are as follows:

- $3Cu_2O + FeS \rightarrow FeO + SO_2 + 6Cu$
- $5CuO + CuFeS_2 \rightarrow FeO + 2SO_2 + 6Cu$
- $3CuO + CuFeS_2 \rightarrow FeO + SO_2 + 3Cu$
- $2CuO + S \rightarrow SO_2 + 2Cu$ (S and FeS originate from decomposition of the pyrite. Cu_2O and CuO are products derived from the roasting phase.)

The iron oxide continually formed is absorbed by combining with the silica (SiO_2) to form the fayalite slag, driving the equilibrium to the right. As can be seen, a large amount of copper oxides is needed as compared with the amount of chalcopyrite. At Craddock's request, Rostoker prepared a "recipe" for carrying out a similar process for smelting chalcopyrite, but producing no slag. He suggested roasting bean-sized pieces of chalcopyrite until the surface is dead-roasted, crushing the product (which he seems to assume would be copper oxide on the outside with chalcopyrite remaining inside), then smelting all together. (On the basis of Doonan's experimentation, already described, during roasting, the inside of chalcopyrite nodules, far from remaining unaffected, partially reduced to copper metal, which should enhance the desired result.) As an alternative possibility, Rostoker recommended first dividing the ore into correctly-sized portions, roasting the larger one in an open crucible, then mixing in the other portion, closing the crucible and smelting on a simple hearth covered with charcoal. (Craddock 1995, 137)

Because chalcopyrite melts at 880°C, above that temperature it could perform part of the function of molten slag in the conventional method, by allowing forming copper to sink to the bottom of the crucible. (*ibid*)

Craddock believes that all the copper minerals which could be identified in ore, both oxidic and sulphidic, were smelted together in the earliest, simple process used in the British Bronze Age. This does seem to have been the case at the Great Orme probable smelting site, where remains of both malachite and chalcopyrite have been found together (Roberts 2002, 31), which might have made it possible to smelt sulphidic ores directly, without any pre-smelting roast, as the oxides present might have contributed their oxygen to the formation of sulphur dioxide and copper from the sulphide ores, as suggested by the simplified equation previously shown: $5CuO + CuFeS_2 \rightarrow FeO + 2SO_2 + 6Cu$ (Doonan 1994, 88). Some of the examples already recounted seem to hint at a merging of the roasting and smelting processes, which might have occurred in this way.

In his theory of Bronze Age copper smelting in the British Isles, Craddock is rather unclear about the temperature level that would be required for the mostly slagless, poorly reducing method he postulates. However, Paul Budd (1993, 33-7) developed a theory that the arsenical copper, of which most of the earliest copper artefacts from the British Isles were made, must have been smelted by a method using temperatures no higher than about 900°C. Earlier work, by Coghlan and Case and others, had shown that early arsenical copper artefacts never contained more than 5% arsenic. However, if arsenic and copper were heated together experimentally under reducing conditions to around 1000°C, the forming copper-arsenic alloy would melt and the remaining arsenic would quickly diffuse into the alloy, raising the arsenic content as high as 9%. If the temperature were maintained at less than 900°C, there would be no melting, and the slower diffusion of arsenic vapour into the solid copper would always produce an alloy with no more than 5% arsenic. Richard Thomas's experiments had shown that copper arsenate ores can be easily smelted to form arsenical copper alloy at temperatures as low as 700°C. From all of this evidence Budd concluded that a low temperature (700-900°C) smelting method must have been in use in the earliest part of the Bronze Age. More recently, though, following experimentation, Budd believes he was wrong about this, as the copper which formed at such low temperatures was too finely dispersed throughout the solid mass of reacting material to be separated out (P. Budd, pers. comm.). Nevertheless, further research on this matter might be useful, since it is not possible now to know all the conditions involved in Bronze Age smelting, and small changes in procedure might make considerable differences.

Craddock puts forward three possibilities to answer why there has been such a failure to find slag heaps at mine sites in the British Isles: 1) "the slag once existed, but has since decayed or been removed", 2) "the slag exists but at some distance from the mine sites and so has not yet been located", and 3) "the very primitive processes used in the Bronze Age did not produce slag in any quantity" (Craddock 1990, 69). The first of these possibilities can probably be discounted as unlikely, for the reasons Craddock gives, that conventional slag is very durable and would not have decayed over the millennia since it was deposited, and that it has little use, so would not all have been removed. Possibilities 2 and 3, however, may be about equally likely, since there are indeed many unexplored areas in the wider vicinity of early mines where slag heaps could be hiding; early smelting places in some other parts of the world were sometimes located at a distance from their ore sources; and Craddock's theory cannot be considered proven fact, although seemingly supported by quite a bit of evidence. However, when investigating whether burnt mounds might have been copper smelters, there is no option but to go with Craddock's theory, because the simple hearths of burnt mound sites could correspond to no smelters known other than those of the earliest, simplest method, and if the mounds at burnt mound sites were conventional slag heaps, they would have been so identified by archaeologists long ago. Therefore, when comparing burnt mound sites with smelting sites, it will be those of the simplest type as described by Craddock, that are intended.

Parallels between Bronze Age Copper Production and Burnt Mounds

Is there any relationship between the principal features of burnt mound sites and what is known about Bronze Age copper production? Much more research needs to be done before an answer other than "possibly" can be given to that question. However, at this point some parallels can be noted, which may or may not ultimately prove to be meaningful.

Perhaps the most obvious point of similarity between burnt mounds and Bronze Age copper processing sites is their common location almost always near a stream. Herdits' quote about east Austrian smelting sites has already been noted. In their description of smelting sites in northwest India, Hegde and Erickson (1985, 63) state, "The finely crushed ore was concentrated by gravity separation at the smelting sites which were invariably located near the banks of hill streams". In the Near East, the Feinan and Timna ore-processing sites were close to wadis and to the confluence with other wadis which made the prospect of water more likely. (Weisberger 2003, 78) In northwest China, Mei and Li (2003, 114) describe a copper smelting site cut into two areas "by mountain torrents". In Ireland, there is a stream close to the supposed ore-processing site beside Mt. Gabriel's Mine 3, which O'Brien (1994, 103) excavated. Why was a continual source of water so needed at Bronze Age copper processing sites? Several references, already mentioned, have suggested that water was required for beneficiation, and for two different reasons: 1) for removing dust from ore pieces as they are crushed, thus making the mineralization in them more visible for sorting, and/or 2) for gravity separation of wanted minerals from gangue during or after the crushing process. Likewise, some sources have suggested uses for water in the roasting and smelting processes: 1) to cool the hot ore or hot metal and slag following the procedure, and 2) to help separate the roasted ore or newly formed metal from other materials with which it is mixed at the end of the process, such as ash, charcoal, and, in the case of smelting, unreacted materials and other products of the reaction. Both of these purposes could be accomplished by moving all the remains of the heating process into a tank of water. This might also protect hot copper from oxidation as it cools.

Now the possible purposes of the water trough, an identifying feature of burnt mound sites, become clear, if burnt mounds were actually copper processing sites. Although water was freely available in the stream nearby, most of the above suggested uses for water would probably be better carried out in a container, in order to prevent any copper or copper-bearing minerals being carried away and lost in the stream. Copper must have been very precious in the Bronze Age, and required so much in terms of labour and resources to produce, that great care must have been taken to lose as little as possible. The probable water trough at Mt. Gabriel and the pit beside the roasting bed at Mühlbach may be examples of such water container use at ore-processing sites.

The stream would have provided water for other uses one can think of as well, such as fire control and drinking water for the workers. The apparent preference for siting burnt mounds close to the spring from which the stream issues might have been to take advantage of any pieces of copper mineral-bearing rock the spring might throw out. It seems unlikely, though, that this could have been a major source of ore.

Moving on to the hearth feature usually found at burnt mound sites, there is generally a simple open hearth, often about 1 meter in diameter with perhaps some stones lying randomly around the perimeter. It bears some resemblance to the open hearths of the simplest forms of smelters cited by Craddock at the Feinan Chalcolithic and southeastern Spanish sites. However, evidence of crucibles having been used is almost non-existent at burnt mound sites in the British Isles (although crucibles and even casting moulds are sometimes found at burnt mound sites in Sweden) (Larsson 1990, 144). In the British Isles burnt mound hearths might have been used for roasting only, with the product transferred elsewhere for smelting. Or possibly smelting could have taken place directly in the hearth. Conceivably, there was no roasting step in the process being used, roasting being merged into smelting, as already suggested. It is possible there could be a relationship between the Beaker period pits at Ross Island, in which smelting is thought to have occurred (O'Brien 2004, 223-67), and the small "fire pits" found under some burnt flint mounds in Norfolk, also with Beaker dates and pottery. (Bates and Wiltshire *et al.* 2000; Crowson 1995)

Turning to the burnt stones, which form the bulk of what is visible at unexcavated burnt mound sites, what could their function possibly have been, if these were copper production sites? They are not found at any of the known ore-processing sites already considered, except at Great Orme, so if burnt mounds are copper processing sites, then the fire-crazed stones may represent a northern European innovation, and a modification of the simplest copper-making sites found farther south. These stones can hardly be the remains of the ore from which the copper has been extracted, because they have not been subjected to any crushing, and their texture has been changed by exposure to fire. They might have served some refractory purpose. For example, they might have been built into a rudimentary, temporary structure in the hearth and around the ore, perhaps held in place or lined with mud, to increase reduction possibilities. Such a structure would have had to be broken down after each smelting in order to retrieve the products.

The following chapters will attempt to throw further light on the possibility of a relationship between burnt mound and copper processing sites.

Chapter 3

CHARACTERISTICS OF BURNT MOUND SITES

The first of the three projects aimed at determining whether burnt mound sites might have been ore-processing places was a detailed examination of the characteristics of such sites. It was hoped that some characteristics might be identified which would either strongly support or essentially rule out metallurgical uses for either all or some groups of burnt mound sites, or that the overall tendency of the characteristics would lean more in one direction than the other.

Methodology

The technique chosen for this study is adapted from social and other sciences (Sjoberg and Nett 1968, 129-59), where it begins with collecting specific items of information from a random sample of the population under study; the sample consisting of enough cases to permit the identification of significant sub-groups within the population. The answers collected from all sampled persons are then counted for each item of information requested, after which any relationships between the answers given for the various items are explored.

Applying this method to "interrogating" burnt mound sites, first a sample had to be selected, as randomly as possible, theoretically from the population of all excavated burnt mounds in the British Isles, but actually from all those found in a search of the published literature. Since the population from which it is drawn is relatively small (perhaps about 300) for this type of study, and for some members almost no information is available, the sample has not been randomly selected, but rather, to ensure geographic and chronological spread, and also a large enough number of sites so that the concentration of results would be accurately represented, and that there would be a reasonable number of examples for most subgroups detected. A sample of 65 burnt mound sites was ultimately selected, which is shown in Table 3-1.

After selection of the sample, the next step was preparation of a data sheet in order to collect the same types of information on all selected sites, insofar as it was available. Along with much general information, some items were included because it was thought that they could have a particular bearing on the metallurgical potential of the sites. A sample data sheet may be found in the Appendix.

When the data sheets for all sites were filled in with material from published sources, the information was transferred to a database consisting of a series of tables, each table listing all selected mounds and representing a different aspect of the sites, such as terrain; mound, trough, and hearth characteristics; finds; and surrounding features. In these initial tables the sites were listed according to region (Scotland, England, Isle of Man, Wales, and Ireland), and, within each region, roughly from north to south (as they are in Table 3-1). This arrangement was made because every site had a location of this kind, while, for all other characteristics, some sites lacked information, and an immediate comparison on a geographical basis was then available with all other characteristics. Later, for comparisons against other characteristics, the sites were regrouped accordingly and additional tables prepared. The sites having each characteristic were then totalled. The outcomes of this process are described below.

General Results

In this section all pertinent results are presented and discussed, except those dealing with changes over time, which will be covered in a later section.

Terrain

Elevation: Twenty-seven sites in the sample have a numerical elevation indicated. Of these elevations, the highest is 300m, and the lowest, 0.4m above sea level. The average is 130m, and the median, 100 m above sea level, showing that more of the sites are below the average than are above it. Of the sites with no specified numerical elevation, there are some qualitative indications. In 5 such cases, the site is said to be "low-lying"; in 4 others, "in a valley"; and 3 more, "on a seacoast". In only one case a high elevation is suggested – "an upland area", but that site has an elevation of only 200m above sea level. The overall impression is that burnt mounds generally are found at moderate elevations, some quite low, and virtually none high in the mountains.

Slope: Of 35 sites where one can distinguish whether the mound was created on level or sloping ground, 27 are on a slope and 8 are on the level, more than 3 to 1 in favour of a sloping location. Typically, under the mound the hearth is found slightly higher than the trough, which itself is a bit above the stream or other water

Table 3-1: Burnt Mound Sites in the Study Sample

Burnt Mound Name	Location (County)	Principal Reference(s)
	Scotland	
Tangwick	Shetland	Moore and Wilson *et al.* 1999
Tougs	Shetland	Hedges 1986
Beaquoy	Orkney	Hedges 1975
Liddle	Orkney	Hedges 1975
Beechwood Farm 1	Highland	Cressey and Strachan 2003
Ceann nan Clachan	Western Isles	Armit and Braby *et al.* 2002
Clydesdale North	South Lanarkshire	Banks *et al.* 1999
Clydesdale South	South Lanarkshire	Banks *et al.* 1999
Dervaird	Dumfries & Galloway	Russell-White 1990
Auld Taggart 4	Dumfries & Galloway	Russell-White 1990
Machrie North 8	North Ayrshire	Barber and Lehane 1990
	England	
Titlington Mount 1	Northumberland	Topping 1998
Titlington Mount 2	Northumberland	Topping 1998
Sparrowmire	Cumbria	Heawood and Huckerby 2002
Waycar	Nottinghamshire	Garton 1993
Holme Dyke	Nottinghamshire	Elliott and Knight 1998
Willington Quarry 1	Derbyshire	Beamish 2001
Willington Quarry 2	Derbyshire	Beamish 2001
Milwich	Staffordshire	Welch 1997
Castle Donington 1	Leicestershire	Coward and Ripper 1999; Beamish and Ripper 2000
Birstall	Leicestershire	Ripper 1997; Clay 1999; Beamish and Ripper 2000
Rodway	Shropshire	Hannaford 1999
Cob Lane	Birmingham	Barfield and Hodder 1981, 1982 and 1987; Hodder 1990
Feltwell Anchor	Norfolk	Bates and Wiltshire *et al.* 2000
Buckenham Tofts 1	Norfolk	Layard 1922
Buckenham Tofts 2	Norfolk	Layard 1922
Swales Fen	Suffolk	Martin 1988
Sandy Lane	Gloucestershire	Leah and Young 2001
Phillimores	Greater London	Moore *et al.* 2003
Phoenix Wharf	Greater London	Bowsher 1991

Burnt Mound Name	**Location (County)**	**Principal Reference(s)**
Deadman Bottom	Hampshire	Pasmore and Pallister 1967
Bestwall	Dorset	Ladle and Woodward 2003
	Isle of Man	
Clay Head I	Isle of Man	Cubbon 1964 and 1974
Clay Head III	Isle of Man	Cubbon 1964 and 1974
	Wales	
Rhosgoch 6	Anglesey	White 1977
Bryn Cefni	Anglesey	Smith and Kenney 2002
Nant Porth	Gwynedd	Davidson 1998
Graeanog	Gwynedd	Kelly 1990 and 1992
Felin Fulbrook	Ceredigion	Williams 1987
Morfa Mawr 2	Ceredigion	Williams 1985
Carne A	Pembrokeshire	James 1986
Carne B	Pembrokeshire	James 1986
	Ireland & N. Ireland	
Ballycroghan I	Down	Hodges 1955
Ballycroghan IIa	Down	Hodges 1955
Ballycroghan IIb	Down	Hodges 1955
Ballycroghan III	Down	Hodges 1955
Island Magee	Antrim	Duffy and James 2000
Curraghtarsna	Tipperary	Buckley 1985
Webbsborough 1	Kilkenny	Prendergast 1955
Ballyhimmin	Kilkenny	Prendergast 1977
Catstown1	Kilkenny	Ryan 1990
Raheen	Limerick	Gowen 1988
Peter Street	Waterford	Walsh 1990
Clonkerdon	Waterford	Quinlan 1886
Rath More	Kerry	Ryan 1976
Imlagh Basin	Kerry	Mitchell 1989 and 1990
Coarhamore	Kerry	Sheehan 1990
Castleredmond	Cork	Doody 1987
Kilcor South IV	Cork	Hurley 1987b
Killeens I	Cork	O'Kelly 1954
Killeens II	Cork	O'Kelly 1954
Ballyvourney II	Cork	O'Kelly 1954
Ballyvourney I	Cork	O'Kelly 1954
Clashroe	Cork	Hurley 1987a
Drombeg	Cork	Fahy 1960; Power (ed.) 1992

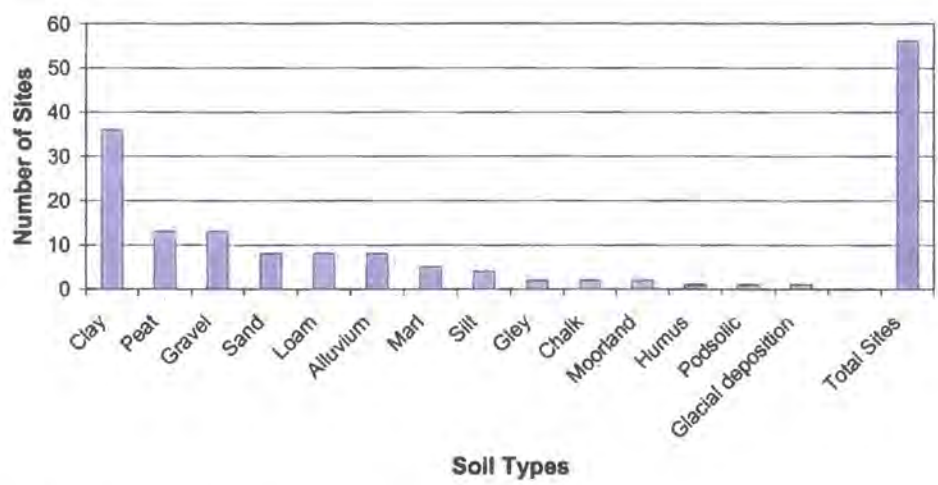
Note: As it would be too cumbersome to list all the references for all the sites included in the counts for every succeeding listing, table or figure, the references shown here will serve as the references to these sites for the remainder of the chapter.

source. Perhaps this arrangement is important enough for the operations undertaken there, that sloping locations may have been deliberately chosen for this particular quality.

Twenty-three of the sites are on ground which is raised above its surroundings. Of these, 11 are on ground slightly raised above surrounding marsh, and 2 on similarly raised ground at seacoast locations, while 3 others are on rocky promontories rather high above seacoasts. Seven additional mounds are on low hillocks, in 2 cases sandhills and in 5 cases, clay. Probably so many sites were located on raised ground to provide a convenient work area and a dry place for a fire within a generally wet environment, which was considered necessary for the sake of a continuous water supply.

Local Soil: The types of soil, as described by the excavators, which were found at the sample burnt mound sites are shown in Figure 3-1.

Figure 3-1: Local Soil Types



The total for all types listed is more than the number of sites with information on this point (56), because for some sites 2-6 different soil types were mentioned.

The overwhelming choice of soil on which to locate a burnt mound site was clay (although in 7 cases the clay is under, and in at least 3 cases over, something else). Given that much of the United Kingdom was covered with glaciers which produced glacial clay subsoil, this is not unexpected. However, in 9 cases, a patch of clay was chosen for the site in an area where much of the surrounding soil was not clay, and in at least one of those cases the excavator thought the clay had been deliberately deposited there. Two possible reasons for the choice of clay soil quickly come to mind. The water-holding property of clay would probably have provided the optimum foundation for the trough, and the hardening of the clay when heated to a high temperature, forming a pottery-like surface, would have made a serviceable hearth.

Water Source: At 45 sites (of 63 with some information) a stream was identified as the most likely source of the water needed for the operations carried out at the site. In 23 of these cases, an old stream bed, now no longer functioning, was thought to have been the water source. In 9 other cases, the surrounding bog was considered the principal water source in the absence of an identifiable stream bed. In 6 cases a river was the likely source, although in one of those the distance to the river is about 46 m., quite far when the extreme closeness of most mounds to water indicates a need for large amounts to be close at hand at all times when the site was in use. In one case the water source was a pond, and in another, a well built around a spring, perhaps to make more of its water more immediately available for operations at the site, a drain removing the overflow. In 3 cases no water source is known, although in one of those it could have been occasional flooding.

There were 21 cases where the water source was said to be "near" the mound, but no specific distance was indicated. Thirty-two of the 41 mounds with a known distance – 78% – at the time of excavation were within 5m of their water source, and 28 of those – 68% - were within 1m of it. Here it must be taken into account that much erosion of both stream banks and mounds has occurred since the time when the mounds were created, often bringing the streams and mounds ever closer to each other, and in some cases actually merging them. Still, most must have been very conveniently close even at the beginning.

Though it has been suggested (T. Laurie, pers. comm.) that burnt mounds were preferentially located close to the spring from which their stream water source issued, only in 12 of the sample cases was a spring mentioned, really too few from which to generalize. If true, however, a preference for closeness to a spring could be related to the function of the site; certainly it would help to explain why streams were clearly favoured over bigger and still bodies of water. Possibly the people who built the sites wanted the clearest, purest water they could obtain, or perhaps for their purposes constantly flowing water was preferable.

Mounds

Mound Shape: The typical burnt mound is usually considered to be crescent-shaped, and this does seem to be borne out to some extent. Of the 65 in the sample, 24 were roughly crescent-shaped; 11, circular; 7, oval; and in 23 cases the original shape was unclear due to the large amount of disturbance, destruction or erosion which had occurred. However, as the mounds were likely formed by randomly throwing or depositing used burnt stones and other waste materials onto the periphery of the site's operational centre, the mound shape is probably not very important.

Mound Dimensions: A summary of the dimensions, where known, of the sample mounds is shown in Table 3-2. It is clear that the size varies greatly from one mound to another, probably depending on how many times each site was used, and possibly how and for what purpose each was used, as well as the extent to which each mound has been eroded and otherwise disturbed. There appears to be no relationship between mound size and any aspects of its location, or any trend over time.

Table 3-2: Mound Dimensions

Dimension	Number of Sites	Average	Median	Highest	Lowest
Diameter	12	12.84m	12m	20m	5.6m
Length	35	12.06m	12m	26m	2.6m
Width	33	8.18m	8m	21m	1.5m
Height	27	0.7m		2m	0.1m

Vegetation on and off the Mound: Again, an attempt was made to test another theory: that the vegetation on the mound differs from that surrounding it. In only 12 cases were the types of vegetation both on and around the mound indicated, so the results are not necessarily representative of the sample as a whole; however, in 11 cases out of 12 the vegetation differed, suggesting that the theory might be valid. To the extent that it is, the reason is probably mainly the generally wetter environment (producing marshy vegetation) which often surrounds the mound compared with that on top of it, due to the higher elevation of the mound top and better drainage caused by the combination of materials within it (see below). However, to some degree it is possible that the different type of vegetation which grows on the mound is due to different nutrients available to it from the mound material (Sutcliffe 1971, 4-6).

Mound Material

Burnt Stones: The most defining element in the mound material is the brittle, fire-cracked stones. Table 3-3 compares the types of stone found in the mound material with local rock types found at or very near the sites, so from it some insight may be gained into types of rock considered particularly desirable or undesirable to use in the heating process carried out at these sites. In the table, note that the total number of cases in each column does not equal the total of the rock types listed because more than one rock type occurs at some sites. Also, the totals in the two columns are different, which must be taken into account in comparing the items in them.

Table 3-3: Types of Local Rock and Burnt Stones

Rock Types	Local Rock (Number of Sites)	Burnt Stones (Number of Sites)
Igneous	9	7
Metamorphic	3	3
Sedimentary:		
Sandstone	12	21
Flint	1	9
Limestone	3	3
Shale	13	1
Other sedimentary	15	2
Total sites with information	31	42
Sites with no information	34	23

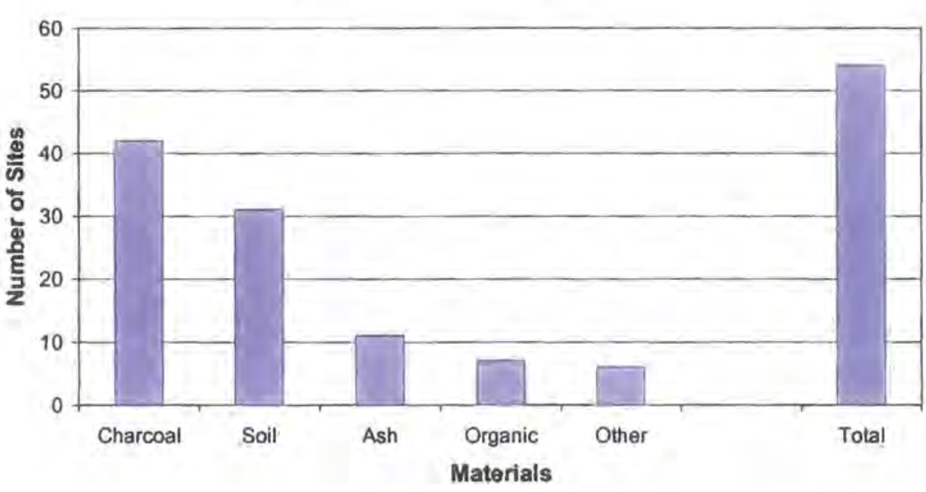
Overall, it looks as if the relatively small numbers for igneous and metamorphic rock remain fairly constant between local availability and use at burnt mound sites, but this impression is somewhat deceptive. In only 4 cases was igneous rock (basalt, quartz, granite, dolomites, rhyolites, etc.) both available and used at the same site (3 in Wales and 1 in England). Those sites where igneous rock was used but not locally available (3), and vice versa (5), are all in Scotland (4) and Ireland (4). The situation is not a simple one, but in general it seems that igneous rock was not greatly sought, as might have been expected due to its hardness, for use at burnt mound sites, but was sometimes used if available, and in a few cases was deliberately imported. Although it is hard, some igneous rock may suffer thermal shock well, but break up after several heatings, so is not necessarily the best choice for a thermally resistant purpose (C. Caple, pers. comm.). For metamorphic rock (slate), there are 2 cases where it was available and used, as well as one each where it was available and not used, and vice versa.

Sedimentary rock appears to be much more readily available than igneous and metamorphic, so it is not too surprising that it was more often used, even though a preference for a harder rock for heating purposes might be expected. Within the sedimentary category, sandstone and flint were both used at more sites than those where they were mentioned as available, and shale was clearly avoided, as were the types listed as "other sedimentary" (including chalk, marl, mudstone, siltstone, etc.) which would surely disintegrate quickly when exposed to high heat. In every case in the sample where sandstone is a known available rock, it was found in the mound material. Sandstone was frequently used in burnt mounds in every part of the British Isles except southern England, where flint was the stone of choice, undoubtedly based on its much greater availability there. All 9 mounds in the sample using flint are found in the southern half of England. With so much flint needed for the creation of a burnt mound, and so little indication of its availability in the immediate vicinity of the mounds where it was used, could it have sometimes come from the flint mines, such as Grimes Graves, which were also in that region? This conjecture raises questions of possible exchange networks between operators of burnt mound sites and flint mines; e.g., what product from the burnt mound sites might have been exchanged for the flint? In summary, the most thermally resistant rock types readily available seem usually to have been used for heating at burnt mound sites, deliberately avoiding the softer sedimentary types such as shale, with flint the dominant type used in southern England and sandstone, virtually everywhere else.

Matrix: The matrix consists of everything else of which the mound is composed, except for the burnt stones. Figure 3-2 shows the most common of these materials and the percent of sites where they are found.

The two substances mentioned in the majority of the reports are charcoal and soil. The charcoal undoubtedly represents remains of the fuel used in the heating process, which was usually either wood or charcoal prepared from wood. But why is soil so often present? One answer is that sedimentary rocks such as sandstone, and to an even greater degree, limestone, after being heated to high temperatures would have a tendency to disintegrate, forming new soil. Also, soil would have settled over a mound after the site's abandonment, some of which could have filtered down between the stones over the millennia since. An additional possibility is that soil was somehow an integral part of the process carried out at the site, just as stones and fuel were. In at least 4 of the cases where ash is mentioned as a component of the matrix, the fuel used was peat. The organic material appeared to be mainly peat and tree remains, and a few nuts and cereal grains. Some of the items in the "other" category may be worth noting; even though each may have appeared in only one or two reports, they could represent minor inclusions which may be more widespread, but usually not noticed or not thought worth mentioning. Burnt clay noted adhering to some burnt stones could suggest a way that some soil became part of the matrix. The "cramp", described by one excavator (Hedges 1975, 42) as often seen at sites where heating took place, looks like white or black plastic, but is actually fused soil, which indicates that an especially high temperature was reached, according to Hedges and Paul Craddock (pers. comm.). However, the other excavator who noted cramp suggests that it is organic and may be the remains of fatty acids from bodies (Banks *et al.* 1999, 14). Green-grey silt may be representative of greenish soils, usually silt or clay, found in various contexts at some burnt mound sites. The colour could probably result from a variety of causes, but among those could be copper or iron compounds.

Figure 3-2: Matrix Materials



Density of Stones vs. Matrix: In 29 cases from the sample sites there is some information about the density of burnt stones as compared with matrix material in the mound: 4 had less than 50% stones; 1, about 50%; and 8, more than 50%. (It is assumed that density by volume rather than weight is meant, as that would be easier to estimate by sight, but in only one report was this specifically stated.) In 12 cases the density is reported as varying in different parts of the mound, and 5 mounds had a particularly high charcoal content. In 4 cases the stones were reported as more dense near the top of the mound (and more matrix near the bottom), and in one case the stones were more dense at the bottom. The numbers are small in this category for drawing conclusions, but it seems likely that there tend to be more stones than matrix and that the matrix, being more fluid, tends to settle toward the bottom, and probably to a greater extent washes away.

Troughs

Troughs and Other Pits: Turning to the features usually found under the mound when it has been excavated, the trough, a water tank cut into the ground surface, often with a structure built inside, is the most defining element which separates the "burnt mound" category of monument from simple rubbish heaps of burnt stones. Often, however, it is difficult to decide whether a pit or depression found under the mound should actually be considered a trough. The opinions of the excavators have been followed where possible, and these often seem to have been based on a roughly geometrical shape, steep sides and a flat base as typical characteristics defining a pit which should be considered a trough.

Table 3-4: Troughs and other Pits

	Definite Troughs	Possible Troughs	Other Pits	No Known Pits
Number of Pits which are:	63	8	35*	-
Number of Sites which have:	54	5	15	5

*At one site the number of pits was indefinite, counted here as one, but certainly more.

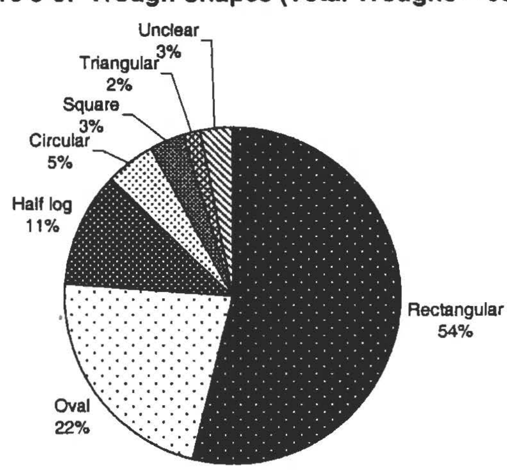
There could be a number of reasons for the lack of a trough. In many cases, the mound was only partially excavated, so there might have been a trough in the unexcavated portion. Table 3-5 gives some idea of the likelihood of this having been the case with the sample sites. At all the sites where there were no pits at all, either less than half the mound was excavated, or the extent of excavation was not made clear. Where there was no obvious trough, but there were other pits, 3 of the 6 sites also fell into those categories. Other reasons for the lack of a trough include the possibility that some pits in the "possible trough" category were in fact troughs (which could apply to at least 2 sample sites), and in some other cases perhaps no remains of what was a trough have survived; for example, due to extensive erosion of the stream bank on which it was located (could apply to at least 2 sample sites). In some cases where two apparent mounds are found close together, they may originally have formed a single mound, so only one of them is found to have a trough (1 possible sample site). In some old reports, written before burnt mounds were well-known, a trough may have been present, but either not recognized by the excavator or not described in a way that is clear to the reader (2 possible sample sites). Finally, it is conceivable that at least one of the sample mounds may be merely a rubbish heap.

Table 3-5: Mound Excavation Extent and Number of Sites with No Trough

Excavation Extent:	Extent <50%	Extent ~50%	Extent >50%	All	Unclear
No pits found	2	0	0	0	3
Pits, but no definite trough	2	1	1	1	1

Trough Shape: From this point through the remainder of this discussion of troughs, only those in the "definite" category will be included, although the other pits will be further discussed in a later section. The shape of the trough is also largely a matter of opinion, as many are more or less irregular, so whether the trough is designated as sub-rectangular or sub-oval, sub-circular or sub-square, is sometimes purely a personal choice. Nevertheless, the majority bear some resemblance to a rectangle, as seen in Figure 3-3.

Figure 3-3: Trough Shapes (Total Troughs = 63)



Trough Construction: The shape of the trough and some of its other features appear to be related to the materials used, if any, for construction within the pit, as shown in Table 3-6.

Table 3-6: Construction Materials and Trough Characteristics by Number of Troughs

Trough Materials	Rect. or Square	Oval or Circ.	Half Log	Other Shape	Clay Lining	Stakeholes Around	Stakeholes Within
Pit only	8	14	-	1(tri.)	4	3	-
All stone Slabs	6	-	-	-	-	1	-
Part stone Slabs	4	-	-	-	1	-	1
Small stones	-	1	-	-	-	-	-
All wood Planks	14	-	-	1(unclear)	1	1	6
Part wood Planks	5	1	2	-	-	-	1
All round Wood	4	-	-	-	-	-	3
Part round Wood	2	1	1	-	-	-	3
All half log	-	-	4	-	-	-	-
Part half log	-	-	3	-	-	-	1
Part withy/ Wattle	-	2	-	-	-	-	-

As can be seen, the oval and circular troughs were all simply pits, without wood or stone construction, except for one lined with small stones, and two others which had withy/ wattle sides and wood bases. Note that these exceptions use materials which easily can be made to fit smoothly around curves, not the case with stone slabs or wood planks, the most common trough construction materials. Four of the 6 troughs with deliberately-placed clay linings were also simple pits; the clay lining could probably be made more securely watertight over a surface of relatively smooth curves than one with corners and crevices. Stakeholes located around the outer edge of 3 simple oval pits suggest an additional possible way the pit could have been made watertight; i.e., by pegging a covering, such as an animal skin, over it. (There are, of course, other possible uses for such stakeholes; for example, for creating a shelter over the trough area.) On the other hand, all but 1 of the cases where stakeholes were found within troughs (12) were in rectangular pits where some wood (or in one case, stone) construction existed, and where stakes appear to have been used to help hold the corners, and sometimes mid-sides, of the construction in place. Most of the troughs with wood or stone slab structures were rectangular or square, but 8 of the pits having no construction within were also rectangular, and at least some of these may have had wood-built troughs within originally, which, due to environmental conditions, have totally disappeared. (A few of those where a wood trough has been claimed were found with only the "ghost" of wood planks remaining on the pit sides.)

Stone slab construction predominated in the Scottish Isles (3 of the 4 sites with troughs; the other was a pit with clay lining) where wood was especially scarce, which suggests that the choice of construction material was largely dependent on local availability. Five of the troughs created from hollowed-out half logs were found in Ireland, and one each in England and Scotland. As the British ones were in eastern locations, it does not seem too likely that there was direct technology sharing between their makers and those in Ireland. There appeared to be no clear geographical relationship to other trough types. In summary, considerable thought must have been given in advance to the most appropriate method of trough construction to be used at each site and the trough pit was shaped accordingly.

Where different trough phases were noted at the same site, they were counted as different and separate troughs only if they occupied different areas. At 7 sample sites, however, two separate troughs were found under the one mound, and at one site, three troughs were found. In all 7 of the 2-trough sites, there is some evidence suggesting that one trough was created earlier than the other. Table 3-7 shows the differences in shape and trough construction between the earlier and later troughs at these sites.

Table 3-7: Two-trough Sites

Site Name	Primary Trough Shape	Primary Materials	Secondary Trough Shape	Secondary Materials
Killeens II	Half log	Half log	Rectangular	Wood planks
Titlington 2	Oval	Pit only	Oval	Pit only
Clay Head I	Circular	Pit only	Rectangular	Stone slabs
Graeanog	Oval (pear)	Pit only	Rectangular	Pit only
Castle Donington	Oval	Pit only	Rectangular	Pit (possibly lined?)
Ballycroghan IIb	Oval	Pit only	Rectangular	Round wood
Raheen	Rectangular	Round wood	Rectangular	Wood planks

This is a small sub-sample from which to draw conclusions, but it appears that the oval, pit-only type of trough tends to be the earlier type in cases where there are two, and the second one at the same site tends to be rectangular and is more likely than the first to have a wood or stone structure within the pit. In some of these cases there is no significant difference in radiocarbon dates between the two troughs, so a possible explanation for the construction differences might be that groups starting a burnt mound operation sometimes may have preferred to begin with a simple pit until they had perfected their technique, after which they may have constructed a new, more complex type of trough. The half-log may also be a similar type of early form, but one case is hardly sufficient for generalizations.

<u>Trough Dimensions</u>: In discussing the dimensions of the troughs, and in the graphs showing those dimensions (Figures 3-4a-c), where the trough is simply a pit, the pit dimensions are used, but where it is a stone- or wood-built trough inside a pit, the dimensions of the structure in the pit are used, unless otherwise indicated. The length of the sample troughs (including diameters of circular ones), based on 56 troughs with dimensions given, is, on average 1.97m, with the longest measuring 4.75m and the shortest, 0.75m The median length is 1.78m, shorter than the average, which suggests that at the high end there are some troughs which are longer or generally larger than would be expected on the basis of a regular progression of lengths, and this is indeed what is shown in the length graph of Figure 3-4a. Examining more closely the longest 10 of these troughs where the lengths make the high end of the graph irregular, we find that 3 are formed from hollowed half logs. Such troughs naturally tend to have longer, narrower shapes than others. Five are pits without any now-observable construction inside, but which might have originally had a wooden trough, which would have made the dimensions somewhat smaller. Another is a pit with a clay lining, in some places 0.4m thick (probably not included in the stated dimensions); and the last, a wooden trough 2.65m long in a 3.8m-long pit, is an example of a few sites where the pit seems oversized, perhaps to allow water to collect from a boggy environment and then to seep into the wood or stone trough to fill it automatically (Hurley 1990, 38).

The widths of the 58 troughs where this information is available averages 1.21m, with a median of 1m (a high value of 3.5m and low of 0.4m), again showing larger than expected values at the high end, also apparently due mainly to pits which

Figure 3-4a: Lengths of Troughs

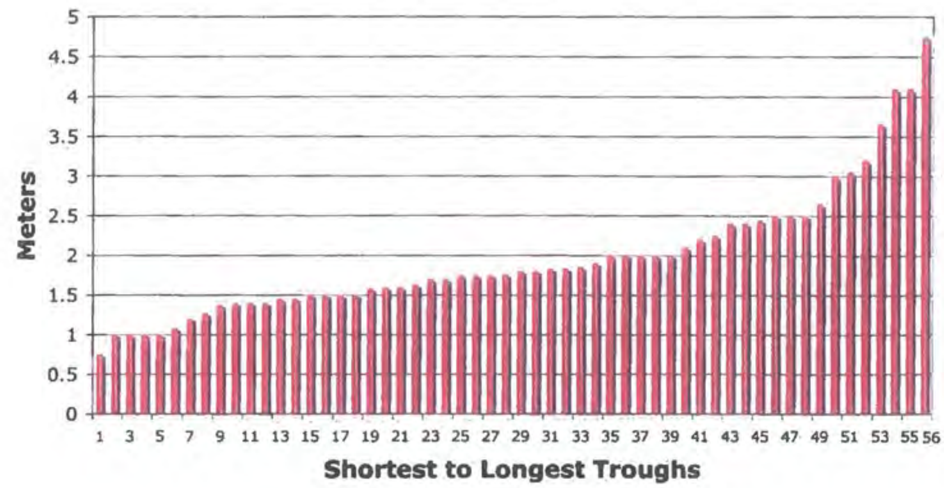


Figure 3-4b: Widths of Troughs

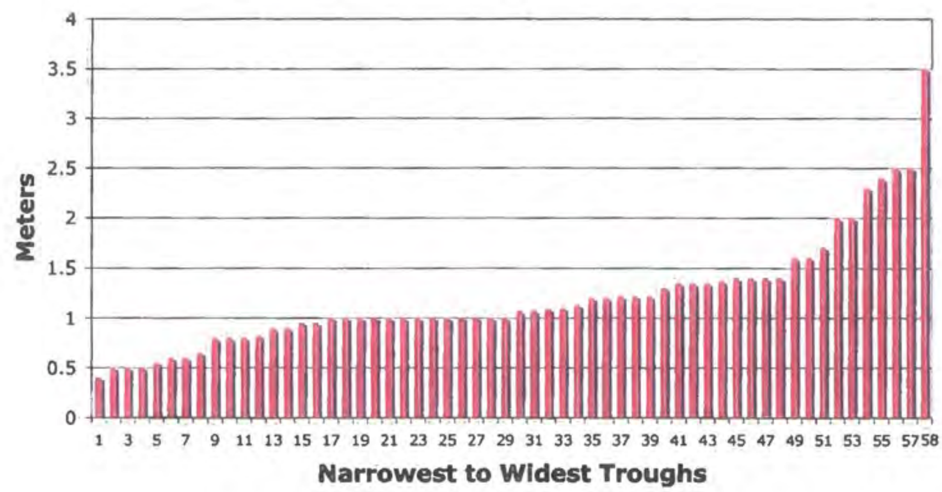
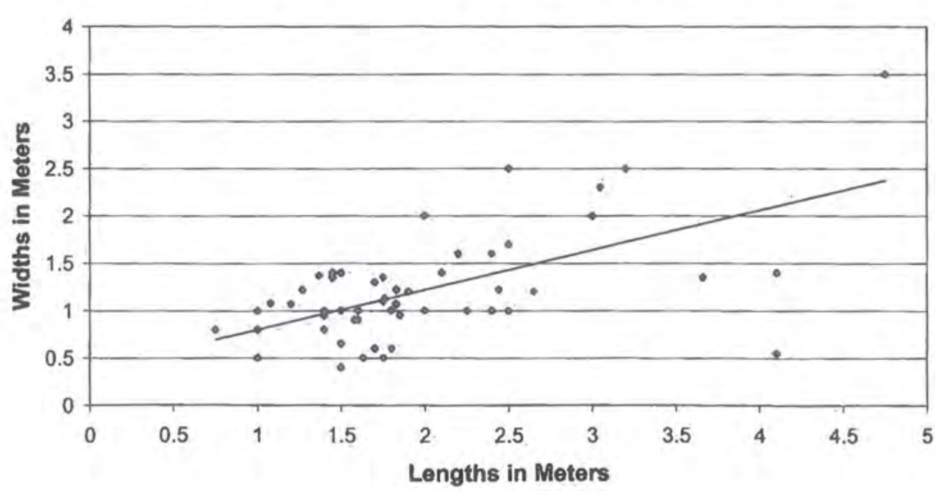


Figure 3-4c: Lengths vs. Widths of Troughs



might originally have had a constructed trough inside. The most striking aspect of the combined widths, however, is the fact that so many cluster very close to the 1m mark. There must be a reason for this, since it certainly is unlikely there was a standard measure at the time these troughs were made equalling the modern meter! One guess is that, with the hearth generally at one end of the trough and frequently a stream at the other end, operations within the trough would usually have been manipulated from the two long sides; therefore, the maximum width of the trough was quite possibly determined by the distance at which a worker could reach every part of the interior of the trough, working from both sides. That distance would likely have been around 1m, given the average depth (based on 52 troughs with information) which was 0.45m. This explanation assumes an industrial use for the site; if this was not the case, the average trough dimensions would have been just right for a bathtub!

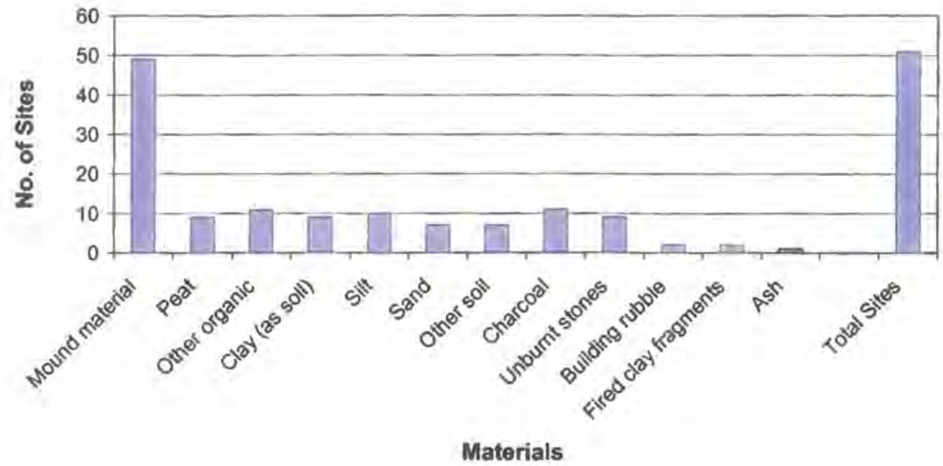
From the scattergram (Figure 3-4c), the average ratio of length to width of troughs is 1.5 to 1. Most troughs cluster between 1m and 2.7m in length and between 0.4m and 1.7m in width. The outliers beyond this cluster divide into two groups: two of the three with larger than average length-to-width ratios are half-logs, while most of those with smaller than average length-to-width ratios are over-sized pits which probably contained structures or linings.

Trough Bases: Troughs were nearly always flat-based with fairly steep sides, these characteristics often used by excavators to decide whether a pit could be classified as a trough. Some features of the flat bases were checked to help evaluate whether troughs could have served as ore-concentration places as part of metal production sites. Several rather simple methods have been used for this step in the ore-preparation process from ancient to modern times. One technique allows a mixture of water and crushed ore to flow down a gently inclined plane, so that the metal-containing bits of the ore, being heaviest, would settle out first. This method may have been used, for example, at the Laurium silver-lead ore-concentration site in Greece (Kepper 2004) and at some early copper smelting sites in India (Hegde and Erickson 1985). In a second method, crushed ore in a sieve was placed in a tank of water and agitated so that the lighter waste material would float free and the metal-containing part would remain in the sieve (Craddock 1995, 164-5). A variant of this method has sometimes been used, although probably less efficiently, without a sieve, by simply putting the crushed ore into agitated water, so that the metal-containing part would be found at the bottom (Hornshaw 1975, 98). Another possibility is the system used in panning for gold, sweeping a dish of crushed ore through water, which washes away the lighter, non-metallic particles (C. Caple, pers. comm.). Checking for the inclined plane possibility, 27 troughs (of 38 with some information on this point) were found to have very level bases as compared with 11 which had some slope, although in all cases quite slight. In view of the fact that many of these troughs were either in boggy ground or close to a stream (or both), some subsidence could certainly be expected over the millennia, so actually the degree of levelness was quite remarkable. This result questions the feasibility of the first ore-concentration method described above. However, a few troughs (3 in Ireland and 1 in England) had "washboard bottoms" made of round wood laid side-by-side (in one case, 2/3rds laid lengthwise and 1/3rd widthwise, with a transverse log separating the two parts). Five other trough bases appeared to have axial indentations. Both of these base types might conceivably have served to help catch and trap particles of metal-bearing ore. The panning method could have been used in a trough, but might have been more effective in a flowing stream, although that would have risked losing some of the copper-bearing particles.

Trough Fill: There are 51 sample troughs with some information about the nature of the fill found in them, and in 49 of those cases burnt mound material (i.e., a mixture of burnt stones, soil and charcoal) was found and generally predominated. It was difficult to know whether all of this material had slumped into the troughs after their abandonment, or in some cases some of it may have been left from the last use or deliberately filled in at the end of use. Other materials mentioned in the reports are indicated in Figure 3-5, although some of them may also have been part of the burnt mound mixture.

Where colours were mentioned they were generally as would be expected of a fill consisting mainly of burnt mound material; i.e., black, grey and brown. However, one case of green-grey silt at the bottom of the trough and another of yellow and blue clay could be worth noting. The trough fills do not show the amount of fine rock particles and silt which would be expected from an ore-washing operation; however, if troughs were used for both the ore-preparation and smelting phases of copper production, or only for the smelting phase to cool and help separate the products of the process, the expected remains from ore-washing might not have been so obvious.

Figure 3-5: Trough Fill

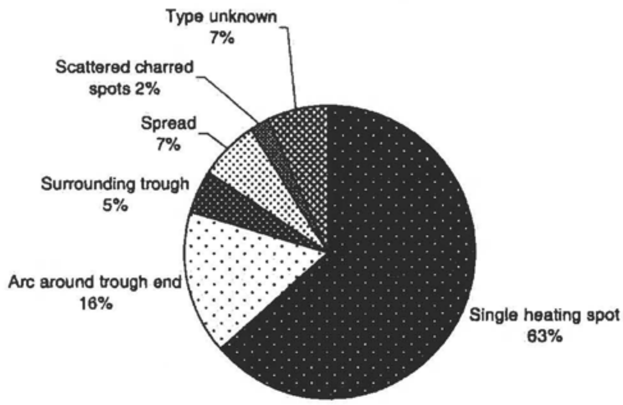


Hearths

Hearth Definition: Hearths should be places where repeated burnings have occurred, but at burnt mound sites, like troughs, are an inexact category, ranging from the definite to the unlikely. Based on the excavator's recognition of a burnt area as a likely hearth, there were 44 reasonably definite hearths at 36 sample sites, including 6 sites with two hearths and one other with three (although, in that case, at least one of the three may have been used for ordinary domestic purposes rather than for the specialized stone heating process). Only hearths in different locations have been counted as separate, and not different phases occupying the same general space. The hearths can be divided into different groupings according to whether the heatings were apparently always carried out in one designated spot, or whether they occurred over a range of associated spots (a "hearth area" rather than a single hearth), as seen in Figure 3-6.

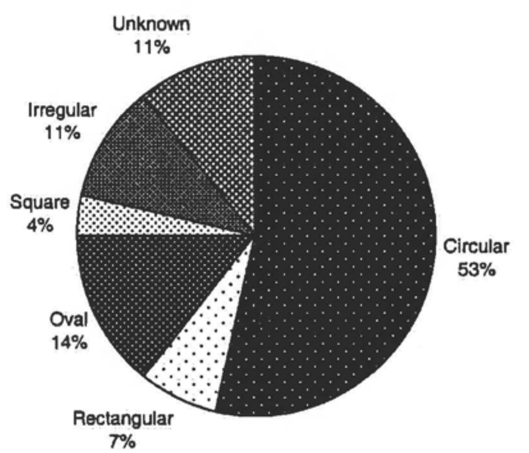
In addition to these rather definite hearths, there were 9 other possible ones at 8 mounds, 4 of these being mounds with no other, more certain, hearth. This makes a total of 40 mounds where some evidence of burning has been found. Of the 25 mounds showing no such evidence, 18 were not fully excavated, so there remains the possibility in those cases that hearths may have been present under the unexcavated portion.

Figure 3-6: Hearth Types (Total Hearths = 44)



Hearth Shape: From Figure 3-7 it seems clear that roughly circular was the most usual shape for hearths of the single heating spot type. (Several of those described by their excavators as having other shapes seemingly could also have been called sub-circular.) The arc type was either roughly crescentic or semi-circular, located at one end (and sometimes extending along the sides) of the trough.

Figure 3-7: Single Heating Spot Hearth Shapes (Total = 28)



Hearth Dimensions: No dimensions were supplied for the type of hearth surrounding the trough. In the one case of scattered charred spots, the spots ranged between $0.3m^2$ and $0.6m^2$ in area, and the one "spread" with information on this point was about $1m^2$ in area. The high and low figures for both the single-spot and the arc hearths show a wide variation in size; however, most single-spot hearths clustered closely around a $1m^2$ area size (15 of the 25 between 1.25m and 0.75 in length measurement; and 18 of the 25, also in width). In about half the single-spot types, a depth measurement was also provided, showing that in at least 12 cases there was some degree of depression of the hearth area below its surroundings. Whether this depression was deliberately dug before the use of the hearth began, or whether it was the result of many occasions when the debris from the fire was cleared away along with some underlying soil, is not clear.

Table 3-8: Hearth Dimensions

Hearth Types	Average Length	Average Width	Average Depth	Longest Length	Shortest Length
Single heating spot	1.14m (25 cases)	0.94m (25 cases)	0.21m (12 cases)	3.42m	0.25m
Arc	3.27m (7 cases)	1.37m (5 cases)	0.08m (1 case)	7m	1.2m

Hearth Boundaries and other Features: At least 17 of the sample hearths were within some sort of stone boundary. In 9 cases this boundary was a wall or line of orthostats enclosing half or more of the hearth, and in the other 8, a simple border of boulders or smallish stones. The base material of the hearth, in 8 of the 9 walled-in hearths was flagstone paving (in 3 cases, three layers of it), and at least 13 hearths were lined with clay (including 4 of those with paving) or made use of a natural clay base. The contents of the hearths, as found and mentioned by excavators, were mound material (19 cases out of a total of 39 with content information), charcoal (14 cases), ash (10 cases), soil (8 cases) and unburnt stones (2 cases). The intensity of the heat produced in the hearths was described in various qualitative ways: reddened base and/or walls or boundary stones (11), burnt area (3), intense heat (2), surrounding slabs or boulders cracked (2), charred clay (3), and oxidized clay (2). In only two cases was a quantitative indication offered: in one arc-type hearth the clay surface was burnt to a depth of 15cms; and in a single-spot hearth, characterized as a "clay pit", the clay was oxidized to a depth of 3-5cms. These figures suggest a wide variation from one hearth to another rather different one, but from only two cases generalization is hardly possible.

Finds

Lithics: Thirty-six of the 65 sample sites (55%) had some sort of lithic evidence. Among lithic artefacts, pounders and hammerstones were of particular interest as they could have been used for crushing ore, and also stone surfaces on which this crushing could have occurred, such as querns and paved areas (the latter probably not usually listed in lithics assemblages, but included here because of the concern with crushing places). However, there were only 8 clear cases of sites where pounding stones were found, and 3 others where there was something (such as a grinding stone) which might have been used for such a purpose. There were 15 cases where querns, a mortar, or flat stone settings were found, one site having both a quern and paving. In addition to the possible ore-crushing lithics already mentioned, other lithics found were as follows:

Type	Number of Sites
Pounding stones	8
Grinding and rubbing stones	3
Querns and mortars	5
Flat stone settings	10
"Pot lids" (flat stone discs)	6
Scrapers	4
Ard shares	4
Spindle whorls	2
Whetstones	2
Perforated stones	2
Axe	1
Shale bracelet	1
Worked flint and flint flakes	22

The worked flint and knapping waste occurred most frequently in England (14 sites of the 22) including at 9 out of 10 sites located from Birmingham to the south, which underlines the far greater use of flint at burnt mound sites in southern England than elsewhere. There could be an outside possibility that the enigmatic pot lids might have served as crucibles, since crucibles used in some contemporary Bronze Age continental smelting sites (Hauptmann 2003, 92) were "almost flat" dishes. Assemblages containing multiple pounders, as well as querns or other stone surfaces and pot lids were all found in 3 of the 4 sites in the Scottish Northern Isles, and many pounders and a quern at the other site there (Tougs); a quern, stone surfaces and a pot lid at Drombeg in Ireland; and a pounder plus a stone setting at Titlington Mount 1 in England. These combinations are normal debris of habitation sites and could have been used for grinding grain or other domestic purposes, but also perhaps for crushing ore. The largest lithic assemblage by far was at Tougs, with 1,457 quartz pieces and 265 "rude stone implements", 15 pumice pieces, and an unusual spoon-shaped implement, in addition to those mentioned above. The second largest was at Sandy Lane: 1,109 pieces, mostly worked flint, with 21 scrapers the only recognizable tools.

Pottery: Pottery was found at 21 of the 65 sample sites (32%), but only in a relatively few cases was it possible to identify a specific type. The most common phrases used by the excavators to describe the pottery were "coarse", "poor quality", "bucket-shaped", "undiagnostic", "abraded", and "decayed". Most potsherds, therefore, were useless for dating purposes; however, taken as a group, the low quality might be suggestive of an industrial use for the sites, although poor quality ware could also be found in a domestic or ceremonial context. One can visualize these rough bucket-type vessels being used to fill the trough with water from the nearby stream, or to bail out the water after use. The following list shows types or periods of those vessels represented which could be identified in some way:

Type of Vessel	Number of Sites
Peterborough	1
Beaker	4
Other EBA	1
Local EBA-MBA	1
MBA	2
Deverel-Rimbury	1
Post Deverel-Rimbury	1
Other LBA	2
BA-IA	1
BA or Early Historic	1
Ceramic mortar (mediaeval)	1

The largest numbers of potsherds found at a single site was 12,101 at Bestwall, many from Deverel-Rimbury vessels, thought by the excavator perhaps to have been an abandonment deposit (Ladle and Woodward 2003, 275). Seven hundred shards were found at Tangwick where they were mainly the remains of three types of vessels: buckets, "more open" vessels, and "shallow bowls". At Sandy Lane the 247 sherds included a few Beaker pieces, but were mainly from the Late Bronze Age. These, however, were exceptional cases. At all other sites there were less than 50 sherds, and in 2 cases, only one.

In addition to potsherds, there were 3 sample sites where other examples of fired clay were found. Two whitish clay spheres, similar to others from such locations as Skara Brae and chambered tombs in the Scottish Isles and Ireland, therefore suggesting a date perhaps as early as the Later Neolithic, were found at

Webbsborough in Ireland on the base of the trough. Pieces of burnt clay were found in the mound material at Waycar (England) and at the Sandy Lane site (also in England), where a clay mould fragment was also found, one of the very few bits of artefactual evidence of metallurgical activity found at sample sites.

Bones: There are 17 sample sites, 26% of the total 65, where some evidence of bone was found. One of the major arguments against the cooking theory of burnt mound site use has been a failure to find bones at most sites, but more than a quarter of the sites is not so few, considering that an unknown number of them are undoubtedly in acidic environments where bones could not survive. However, in 7 of the 17 cases, the amount of bone was too small or too fragmentary to be identified as to either the type of bone or the animal from which it came. The following list shows the number of sites with each identifiable animal species, in some cases several types at a single site:

Species of Bone	Number of Sites
Cattle	9
Pig	2
Sheep	2
Horse	2
Deer	2
Dog	1
Fish and shellfish	2
Human	3

In 2 of the cattle bone cases, only one or two cattle teeth were found. In only one case (Sandy Lane) were there "worked bones", and at none of the sites were there identifiable bone tools. Although bone tools are found at some non-acidic mine sites (Great Orme, Grimes Graves) where they would have been preserved and apparently were used to prise out pieces from the rock surface, they would be less likely to be found at metallurgical sites, where there would not have been a need for the same type of implement. As to the sites with human remains, at one (Feltwell Anchor) there was a secondary human burial cut through the top of the mound, so clearly from a later date than the activity during which the mound was created (also suggested by radiocarbon dating). As to the 2 other sites, at Birstall a skull, apparently decapitated, and some other bones from two young males were found near, but not within, the mound, and at Willington Quarry 2 a human femur was found in a nearby channel interface; so in both these cases it is uncertain whether there was a connection between the human bones and the mound activity. It seems clear that burnt mound sites, as a class, were not created to be burial places.

Only at 3 sample sites in Scotland, 2 in Wales and 1 in Ireland, was any faunal evidence reported (none at the two Isle of Man sites); but in England 11 of the 21 sample sites contained bones. There are at least two possible reasons for the apparent greater incidence of bones in English sites. In England a larger proportion of the area has chalk and limestone as prominent features of the local geology (Dunham *et al.* 1978, 264), creating non-acidic soil conditions which could preserve bone. Also, generally speaking, England was the latest of the parts of the British Isles to develop an interest in the investigation of burnt mounds, so a larger proportion of the excavations of burnt mounds have been carried out in recent decades using modern methods more likely to separate out and identify small bits of faunal matter.

Just as the absence of bones at a burnt mound site does not necessarily mean there were no bones present initially, their presence does not necessarily mean that cooking was its principal function. Within the Great Orme Bronze Age mine complex thousands of bones were found in addition to those that had been worked into mining tools (Roberts 2002, 30); however, no one supposes that cooking was the major purpose of the mine! At any site where people spent long hours at a time, some evidence of eating could well remain. At none of the sample sites was there the abundance of faunal remains which might be strong evidence of large-scale feasting.

<u>Metal, Ore, and Slag</u>: From the sample as a whole, there was very little direct evidence (such as ore, slag, or remnants of newly-made metal) of any metallurgical activity at burnt mound sites. What there was is shown in the following short list:

Type of Material	Number and Names of Sites
Ore	1 – Clay Head I
Slag	1 – Rhosgogh 6
Metal	3 – Clay Head I Killeens I Bestwall

In addition, it should not be forgotten that a clay mould fragment was found at Sandy Lane, but listed under fired clay objects. Three of the 5 items indicated were found at two sites: Rhosgogh 6, located close to Parys Mountain, a Bronze Age copper mine site; and Clay Head I, near a modern copper mining operation. The excavators, in both cases, seem knowledgeable about metallurgy, which is not necessarily true of all archaeologists. The pieces of ore, slag, and amorphous bronze (not identifiable as any object) found at these two sites were all small, and might easily have been overlooked by someone less knowledgeable about metal-making. The ore was determined to be chalcopyrite, and the slag, to have resulted from smelting chalcopyrite. The unidentifiable bit of bronze could possibly have been a remnant from a smelting operation. All three of these items were found in sealed contexts under the mound, so were unlikely to be stray bits from nearby modern mining operations, but could possibly have come from nearby smelting operations contemporary with the activity which created the mounds, if that activity was not itself metallurgical.

One of the other two metal finds may also be instructive, although unlikely to have been the immediate result of smelting. At Killeens I, part of a ring was found under the floor boards of the trough and was thought to have been lost by someone engaged in building the trough. Upon examination and analysis, the ring was found to have been made from gold foil (still present), wrapped around a core of other metal (mostly gone). The bit of core still extant was determined to contain tin. The excavator thought the core might originally have been made of bronze, but there was no trace of copper remaining (O'Kelly 1954, 131). This example suggests one possible explanation as to why, if burnt mound sites were metal-making places, there is so little evidence of copper found when they are excavated. Over the millennia any copper originally present would have been gradually reacting with the materials around it – water, air, soil, etc. – and gradually converted into copper compounds. Many copper compounds are quite soluble, and could have been washed away, leaving little trace.

Organic Matter: In 11 cases vegetable matter, or other organic remains, were found, mostly consisting of grasses, or a few cereal grains or nutshells. A few items may be worthy of note: 1) a degraded oak plank, thought possibly to have formed part of a trough superstructure, found in the nearby paleochannel bed at Beechwood Farm 1; 2) a piece of cord, made of grass twisted together, at Liddle; 3) 64 pieces of birch bark, deliberately peeled off, on the floor of a probable hut (indicated by stakehole pattern) at Ballyvourney I; and 4) a piece of material, thought to be "mineralized leather", between paving stones at Beaquoy. This last might possibly have been a further example of "cramp", already mentioned as soil or organic matter fused by intense heat.

Find Contexts: Table 3-9 shows the contexts of finds where they were identified in the texts. The totals are not total sites, as one site could have several types of artefacts. The columns are totalled simply to provide indices as to which contexts are the most abundant sources of finds. The items found outside the mound are probably less secure in their association with the mound activity than those from other contexts, so it appears that the most fruitful contexts are first, the mound itself, and then the trough and the ground surface under the mound.

Table 3-9: Find Contexts by Number of Sites

Type of Find	Mound Material	Trough	Hearth	Ground Surface	Within Building	In Other Features	Outside Mound
Pottery	10	4	-	2	2	3	2
Lithics	18	8	1	9	5	2	16
Bones	3	5	1	3	-	-	4
Organic	4	1	-	2	1	-	-
Metallurgical	-	3	1	2	-	-	1
Totals	35	21	3	18	8	5	23

Overall, only 29% of the sample sites produced no finds whatsoever. The various regions, however, showed widely differing results: 50% of sample sites in Wales had none; 48%, in Ireland; 27%, in Scotland; and only 5% (1 site) in England. This distribution is probably largely accounted for by two reasons already mentioned: 1) the fact that flint tools and/or knappings were found at most English sites and not often elsewhere, and 2) the late beginning of extensive burnt mound excavation in England as compared with other regions It is surprising how many finds have been made at the sample sites, given the common wisdom that burnt mounds are sites where there are almost no artefacts. They probably acquired this reputation before the inception of modern archaeological methods which are able to detect minute quantities and which include more careful examination of the materials present. However, it does seem to be true that relatively few of the finds of either lithics or pottery are diagnostic.

Surroundings

This section covers three types of features sometimes found in the near or more distant vicinity of the core trough and hearth combination: 1) stone walls enclosing the trough and hearth, 2) possible wood structures, indicated by post- or stake-holes, close to the trough and hearth, and 3) known contemporary sites showing evidence of other human activity within 10 kilometres of each sample burnt mound.

Stone-walled Sites: There are 7 sample sites where some sort of stone wall encloses the trough and hearth, including all the sites in the Scottish Isles (5) where stone was and still is much more available than wood; and also 2 sites in Ireland, where there seems to have been an affinity to the Scottish Isles on the basis of a number of characteristics. These 7 mounds form a sub-group which shows greater complexity than the rest of the sample, but possibly mainly because more remains of what was originally there. Plans of a selection of these sites are shown in Figure 3-8, and an enumeration of some of their special features, most shared by two or more sites, in Table 3-10.

Table 3-10: Features of Stone-walled Sites

Feature	TW	TO	BE	LI	CC	DR	BVI
Two contemporary buildings on site			x			x	
Double boulder skin walls, rubble between		x		x	x	x	
Rubble-built wall			x				
Boulder wall revetted into primary mound	x						
Stone slabs roughly forming a wall							X
No. of cells formed by walls, including hearth	7			8	3	3	
Figure 8 plan					x	x	
Hearth stone-paved	x	x	x		x	x	X
Hearth enclosed on 3 sides	x	x	x	x	x	x	X
"Roasting oven" in addition to hearth						x	X
Extra water container in addition to trough	x		x	x		x	
Down-sloped paved gully with paved basin				x			
"Chute" between trough and hearth	x						
Paved floor within building	x		x	x			
Walkways outside building			x	x		x	X

x = has this feature
TW = Tangwick; TO = Tougs; BE = Beaquoy; LI = Liddle; CC = Ceann nan Clachan; DR = Drombeg; BVI = Ballyvourney I

In Table 3-10 the focus is on features which can be compared and contrasted between sites, and those that may have some relevance to possible metal production; it is not intended to cover all possible features of these complex sites.

On each of two sites there are two separate buildings which are thought to be roughly contemporary. At Beaquoy (where one stone-walled building housed a

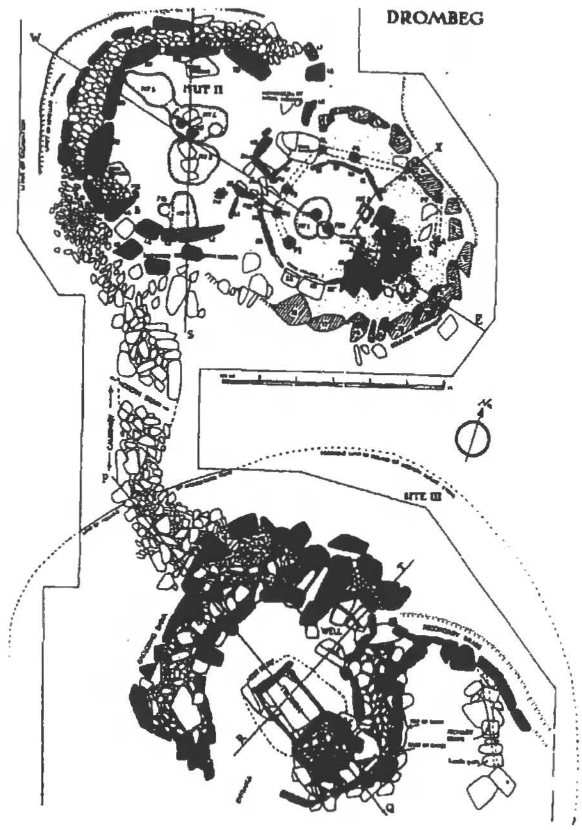


Figure 3-8

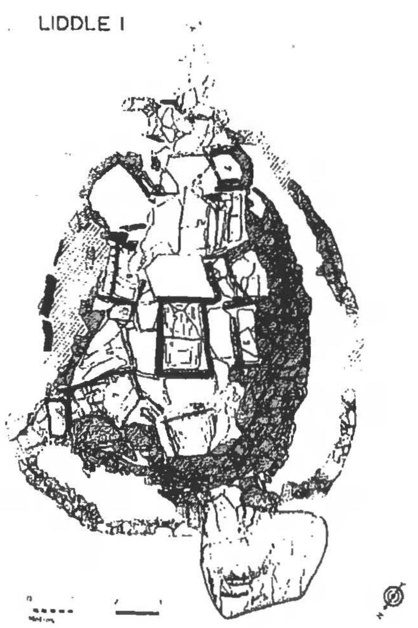
Some Examples of Stone-Walled Complex Sites

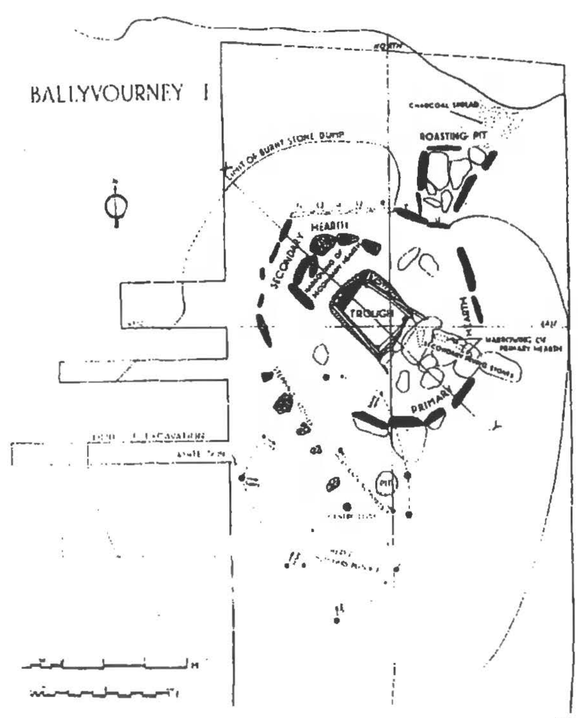
Sources:

Drombeg: Fahy 1960.

Liddle: Hedges 1975, 44.

Ballyvourney I: O'Kelly 1954, 110.





trough and the other a hearth), the hearth building appeared, on the basis of mound stratigraphy, to be slightly earlier, and is designated the primary building, although they are thought to have been used together, or closely successive. At Drombeg the remains of a building designated a hut was found just outside the burnt mound and is considered contemporary with and related to the building under the mound. A paved walkway joined the two buildings. In these two cases, features of both buildings are included in the table. The Tougs site also contained two stone-walled buildings, but their radiocarbon dates are several centuries apart, so they are unlikely to be related, and therefore the building not under the mound is not included here.

The next four lines in Table 3-10 describe the building materials and method of construction of the walls enclosing the trough and hearth. At 4 of the 7 sites, including 3 in Scotland and 1 in Ireland, the walls had a similar structure: two boulder "skins" with a rubble fill between them. In another 4 cases the wall had been formed into several separated cells. In the Northern Isles sites which had these multiple cells, the central, trough-containing, area was bordered all around (except for entrances) by cells, one of which was the hearth. Most of these cells had a floor area of around $1m^2$, although the shapes varied considerably. The cells may have been storage areas, although most were found empty (except for some burnt mound material), or some with an appropriate shape may have served as one-person work areas. An exception to the small size of most cells was Cell G at Tangwick with an area of about $5m^2$, which could have provided work space for several people. In this cell the multi-layered paved floor was covered with green clay, which the excavators said "had to be imported onto the site" (Moore and Wilson *et al.* 1999, 217), because it did not occur in nature locally. Among other possibilities, the green colour could be a result of copper ore crushing and sorting in that cell. At the Ross Island copper production site, green-coloured soil areas were perhaps the most obvious indication of copper having been made there.

The other two cell sites, one in the Western Isles and one in Ireland (the "hut" building, rather than the burnt mound building, at Drombeg), had both undergone a complicated building sequence before acquiring their final form, which was a figure eight, with a hearth as an extra cell at the smaller circle end. These hearths, as well as those at Liddle, Tangwick and the Drombeg burnt mound building, were enclosed by thick walls, except for a limited opening toward the inside of the building, and, in this respect, resembled furnaces more than simple hearths, although there was no obvious arrangement for forced air, as would be expected in a true furnace. If these sites had a metallurgical function, such furnace-hearths might have provided a somewhat better reducing environment than simple hearths.

It will have been noted that the shapes and construction types of these buildings are quite similar to those of houses of the Later Prehistoric period in the Scottish Northern Isles, at such sites as Skara Brae. Major differences are the lack of domestic furnishings, and the position of the trough as the central dominating feature, within the burnt mound buildings. The earlier investigators (e.g., Hedges 1975) referred to these buildings as houses, but more recently a consensus has been developing that they are more likely to have served a non-domestic purpose.

At Ballyvourney I, the excavator interpreted the two arcs of orthostats which nearly enclosed the operational area as enclosures of the large primary hearth areas at both ends of the trough, but here they are treated as forming a wall for the purpose of comparing this very complex site with differently-walled sites of similar complexity. Even in secondary phases the two hearths within the Ballyvourney I enclosure remained simple, though smaller, hearths bounded by boulders, but joined to the outside of the enclosure was an additional orthostat-enclosed structure, opening to the outside and identified by the excavator as a "roasting pit", also essentially the designation given the Drombeg figure-8 building's furnace-hearth by its excavator. These extra heating places might also have been used for the roasting or smelting phases of copper production, if that was a function of the sites.

Also, at four of the sites there was another water container in addition to the single trough usually found under burnt mounds. At the Orkney sites (Beaquoy and Liddle) this container took the form of a tank roughly comparable in size and capacity to the trough, but somewhat differently constructed. At Beaquoy this tank was a cylindrical "quoined well-like structure" (Hedges 1975, 54) located outside the wall at one end of the building surrounding the trough. At Liddle the extra water container was at the opposite end of the building from the hearth, with the trough between the two, and was against the inside of the wall. Outside the wall at that point was a paved, down-sloped "gully", about 1m long, terminating in a large paved basin-like man-made hollow. The excavator said the water tank and the gully-to-hollow combination were parts of the same feature (*ibid*, 43) which implies a connection between them which could only have been through the wall. In the semi-ruined state of the wall the exact nature of the connection must not have been clear. The gully seems likely to have been an overflow drain for the tank (overflow drains were also present at Beaquoy and Drombeg), but why was the hollow carefully created and paved at the bottom of the gully? It looks as if it was considered important to catch and retain whatever came down the gully. Could this combined feature have been used to help separate out metal-containing particles from crushed ore, a much simpler precursor of the ore washing system at Laurium (Kepper 2004)? The extra water containers have been thought to act as cisterns to provide a reserve water supply for the trough, but the question arises as to why such a reserve was needed with a stream nearby.

At Drombeg the burnt mound building and the hut building each had a water container in addition to the trough found under the mound. In the burnt mound building, as mentioned earlier, a "well" had been built into the wall and over a spring, apparently to collect a constant supply of water for the trough. In fact, the presence of the spring and the possibility of constructing the building in this way may well have been the reason for choosing this particular location for the burnt mound operation. In the hut building, where the construction included some wood elements as well as stone, a small water tank had been cut into the floor in front and to the side of the "roasting oven" (or furnace-type hearth). It is thought to have been used for controlling the fire in the "oven" and insuring that it did not spread to and destroy other combustible material.

At Tangwick yet another type of extra water tank was created by adding two stone slabs to the trough to divide it into two compartments, the larger toward the hearth. The excavators thought the smaller compartment might have been used for heating food or drink contained in pottery vessels. Another possibility, if this was a copper production site, is that the smaller section was used for ore concentration, and the larger, for cooling the products of the heating process which took place in the furnace-hearth, these being the two uses suggested for water tanks found at known early copper production sites in other parts of the world (as explained in Chapter 2).

Also at Tangwick there was a "chute", 3.4m long, between the hearth and trough, an indented channel in the paved floor which had clearly been subjected to great heat. Hot material had certainly been removed from the hearth and then pushed along this chute into the trough. Why were the trough and hearth separated so much in this case, when at the majority of burnt mound sites they abut each other or at least are very close? Perhaps the most likely reason for this separation was to protect the workers around the trough from the intense heat of the furnace-hearth. Possibly a similar type of separation is seen in the two figure 8 buildings where the furnace-hearth is distanced by the smaller circular cell from the large circular cell, which seems likely to have been the principal living and/or working area. Another possible reason for the separation might have been to begin the cooling, and perhaps sorting, process along the pavement before the material reached the trough.

In summary, the stone-walled group of sample sites, all complex, all different from each other, but all with some special similarities to others in the group, seem somewhat better adapted to metallurgical purposes than do most of the other sites. The artefact assemblages for this group, previously discussed, also look more appropriate than most others for such purposes.

Posthole and Stakehole Groupings: Postholes or stakeholes have been found and reported at 29 of the sample sites (45%). Of these sites, 22 had only one group of postholes and/or stakeholes (or else a single hole), 6 had two groupings, and 1 had three. Table 3-11 shows either their locations, where they appear to be directly related to the trough or hearth, or their assumed function. Wood-based structures, as evidenced by post- and stakeholes, did not enclose trough and hearth together, as was usually the case with stone-walled buildings, but were generally set off to the side of the trough-hearth combination.

Table 3-11: Posthole and Stakehole Groupings

Type of Group	Definite Groups	Possible Groups	Definite Sites	Possible Sites
Supporting trough structure	7		6	
Around trough edge	4	1	4	1
In hearth	1		1	
Around hearth	4	1	4	1
Formed simple structure	5	5	4	5
Formed substantial building	3		2	
Between simple & substantial	1		1	
Formed furnishings	2		1	
1 hole only	3	1	4	1
2 holes only	1		1	

In Table 3-11, where items are indicated in the "possible" columns, it is due to uncertainty that what was observed was in fact a post- or stakehole, or that either the location or the function is somewhat in doubt. The stakeholes found within or around the trough have already been discussed in the section devoted to that feature. The definite "simple structures" were cases where the stakeholes formed a clear pattern, such as a circle or a fairly straight line. In some of these cases there was other evidence on the ground; for example, an area of white clay or clean sand, or a hollow within the circle formed by the holes. The "possible simple structures" were cases where a group of stakeholes had no clearly discernible pattern but the possibility that all or part of the group might have supported a structure could not be ruled out. Very few substantial buildings were indicated. Two of the three buildings in this category were the first and second phases of the "hut" building at Drombeg, where post- and stakeholes had provided roof support and perhaps originally walls for the smaller and larger circular cells, respectively. The other substantial building was at Bestwall where the post- and stakeholes were within the area enclosed by a C-shaped house gully, which was partly overlain by the burnt mound. This looks as if the house was no longer in use when the burnt mound activity was taking place, but this is not necessarily the case, since at the beginning of the burnt mound operation there would have been little mound accumulation, and after its abandonment the mound material would have slumped down and out to some extent. In one case (Ballyvourney I, which has been described in the stone-walled section) the structure created by a centre post and 10 circumferential ones was judged to be somewhere between simple and substantial. Within it were two other groups of stakeholes, which the excavator thought had supported a bed (4 holes) and a rack (2 holes), but there are certainly other possibilities of types of furnishings which might have been created as well. The two postholes at Liddle were thought to have held door posts at an entrance.

Geographically, only two of the sample sites in Scotland (one in the Northern Isles and one in the south), 18% of the total, had post- or stakeholes; in the remainder of the British Isles, 43.5% in Ireland, 50% in Wales, and 52% in England had them. (In the Isle of Man 100%, or 2 out of 2, had them, but this is too small a number for any meaningful percentage!) This seems a reasonable result, since the Scottish Isles are poor in wood resources, and all sample sites there had buildings created from stone. Roughly half the sample sites in the rest of the British Isles had post- or stakeholes, and in about half of those cases, the holes were probably remains of some sort of building in close proximity to the trough-hearth centre of operations.

<u>Known Nearby Contemporary Sites</u>: Whether burnt mounds were isolated sites or were located close to human habitation, or perhaps to ceremonial places, has been one of the major controversies in burnt mound research. Table 3-12 shows the numbers of other known, roughly contemporary, sites with evidence of human

handiwork, which were reported to be located within 10 kilometres of each sample site. At 9 sample sites no nearby human evidence was reported, so the data in Table 3-12 are based on the 56 sites where nearby sites were reported.

Table 3-12: Types and Distances of Nearby Sites from Sample Sites

Nearby Site Types	No. of Sample Sites with Near Sites	<100m Sample – Near Sites	100-500m Sample - Near	0.5-1km Sample - Near	1-5km	5-10km
Other burnt Mounds	43	11	15	3	7	9
Ritual sites	18	5	2	6	5	3
Domestic sites	11	6	3	2	2	
Artefact find Spots	8		6	2		
Field systems	3		1		2	
Forts	2			1	1	
Mine	1					1

It is clear from Table 3-12 that by far the most likely sites to be found close to a burnt mound are other burnt mounds! Probably the reason for this clustering is that a location which had the requisite natural resources, particularly an appropriate water source, was the most important factor in siting a burnt mound operation, and once someone had found such a location and established one successful operation, others joined in to share the advantages of the favourable environment. There may also have been successive development of new operations as the first mound became too large, encroaching on its working centre, or the trough and hearth became too worn out. Tim Laurie (pers. comm.) has noted that occasionally there is one mound in a group which seems to contain much charcoal, but not many stones, and he thinks it may be an early-created mound from which still-usable stones have been "robbed" to feed into the operation of later-established working sites. It is also noteworthy that 58% of the sample sites with other burnt mounds nearby are within 500m of the nearest others, which means they are likely to be part of a group of mounds; for example, sharing the same stream or system of streams.

The numbers in Table 3-12 represent the number of the sample sites which have one or more of the indicated type of other sites nearby. In some cases the number of those nearby sites is very much larger than one. For example, the maximum number of other burnt mounds near a single sample site is 110 within a

10km radius of Feltwell Anchor in Norfolk! Other instances of large numbers of neighbouring burnt mounds are 25 near Clydesdale North and South, and also 25 near Auld Taggart, both in southern Scotland. Among other types of nearby sites, the numbers near any one sample site are mostly only in single digits, but still the total number of such sites is often larger than the number of sample sites which have such sites nearby, because of more than one of that category of nearby sites close to some of the sample sites.

There are several different types of ritual sites found near the sample sites, so Table 3-13 presents the data for each separate sub-type.

Table 3-13: Types and Distances of Ritual Sites from Sample Sites

Types of Sites	No. Sample Sites near Ritual Sites	No. <100m	No. 100 - 500m	No. 0.5 - 1km	No. 1 – 5km	No. 5 – 10km
Round barrows	3				2	1
Other burials	8	2	1	3	2	
Stone circles	2	1				1
Ring ditches	5	2		1	2	
Standing stones	5			2	2	1
Henges	3				3	
Cursuses	2				2	

As can be seen, the majority of burial sites other than round barrows are within 1 km of sample mounds, while other types of ritual sites are more often farther away. There may be little significance in this finding, but possibly it indicates that these burials, as well as burnt mounds, tended to be somewhat removed from most of the activities of the living, whether of a domestic or ritual nature.

In some cases there are more than one of the subgroup near the same sample mound; for instance, there are 3 stone circles near Machrie North 8. Also, near Carne A and B there are 11 chambered tombs, 10 standing stones and 4 round barrows, all of which give Carne A and Carne B only 1 count each in each of those categories. Ritual sites within 500m of sample sites are 4 burial places, 5 ring ditches, 1 cursus, 1 henge, and a stone circle (this last only 40m from the Drombeg burnt mound).

The domestic sites near sample burnt mounds are divided into single huts or houses (8) and settlements (5), assuming that settlement implies more than one dwelling unit, with one of each near one sample site and two or more settlements near another. All the single houses, except one, were within 100m of a burnt mound site.

(Four of them have been mentioned in the sections just above.) These very close buildings seem likely to be related to the activity at the mound sites, probably as living and/or supplementary working quarters, either temporary or permanent, for those who made use of the burnt mound sites. The settlements, on the other hand, were all more than 100m away from sample sites, two of them more than 1 km distant. It seems that burnt mounds were seldom found in the midst of communities, although sometimes a single family (or other living unit) may have dwelt close by.

Among the artefacts found in the vicinity of sample burnt mounds were two bronze weapon hoards, one a collection of three bronze swords, only partially manufactured, found in the midst of the group of four Ballycroghan burnt mounds; and the other consisting of two weapons and some other items in the Phillimores area of London. It is remotely possible that these, especially the Ballycroghan group, could be products of burnt mound industries. Other finds near sample burnt mounds were an urn with some gold ornaments (Island Magee) and three flint scatters (Island Magee, Felin Fulbrook, and Castle Donington 1).

Changes Over Time

Burnt mounds were being created over a period of at least 2000 years. Having looked at the general characteristics of burnt mounds, the question arises: did the character of burnt mounds change over that period of time? To seek an answer, it was necessary to arrange the sample sites in order of their dates from earliest to latest, and to do that required several manipulations involving the dates.

Radiocarbon Dates: For the majority of the sample sites, radiocarbon dates were available in the literature, but in some cases the dates as given were uncalibrated, so the first step was to calibrate those dates using Oxcal 3.8. The next step was calculating the midpoints of all the calibrated date ranges, so that the midpoints could be used as the basis for constructing a progression from earliest to latest. After this, a graph (Figure 3-9) was drawn showing this progression. Where a site had several dates, and two or more of them had no significant difference, only one of those similar dates was included in order to cut down the total number of dates to place on the graph. Thermoluminescence dates were also included on the graph for two sites which had those, but no radiocarbon dates. Forty-two of the 65 sample sites had one or more quantitative dates which could be graphed as date ranges around midpoints.

Other Dating Evidence: Some sites without quantitative dates had qualitative evidence suggesting a particular period, including diagnostic artefacts, analogy to similar finds from dated sites, stratigraphy, and pollen analysis. In this way 18 additional sites were assigned a date in terms of a general period, such as EBA or MBA-LBA.

Creating a Dating Order for Comparisons: In most cases the sample sites had only one date, or else several dates fairly close together, but a few mounds apparently had two or more phases rather far apart. For comparisons with other characteristics, it seemed best to use only one date for each site; to try to separate all the features of the sites according to what belonged to each phase when only one or two features were clearly dated to a given phase, seemed too complicated to contemplate. Therefore, as a rule of thumb, it was decided to list every site only once in the dating order and according to its earliest date, except in a few cases where the earliest date was based on oak and was much earlier than other dates from the site with which it should have been consistent. In those cases the second earliest date was used. These simplifications may cause some individual inaccuracies, but the overall trends over time should still be observable. The 18 sites with only qualitative dating evidence were added into the dating order at roughly appropriate points, but their names are shown in parentheses in Table 3-14 so that their lesser chance of appearing in accurate dating order may be taken into consideration. In this way a list of 60 out of the 65 sample sites was produced, and has been used in all comparisons of dating order with other characteristics.

The Time Span of Burnt Mounds: From Figure 3-9 it can be seen that the earliest quantitatively-dated of the sample sites dates to around 2700-2600 BC, using the midpoints of the earliest two date ranges (from the same site) on the graph. This places it toward the end of the Later Neolithic period. Following this, the dates proceed quite regularly in unbroken line through the centuries of the Bronze Age down to about 500 BC (barely Early Iron Age in the Scottish Isles and Ireland, where the latest of these sites are located). After that there is a long hiatus, with two more sites appearing to date from about 800 AD to 1200 AD – the mediaeval period. This progression offers assurance that the sample of sites should be quite appropriate for identifying trends over the principal period of burnt mound construction, since it includes good coverage across the entire period.

Figure 3-9: Calibrated Radiocarbon Date Ranges for Sample Burnt Mounds

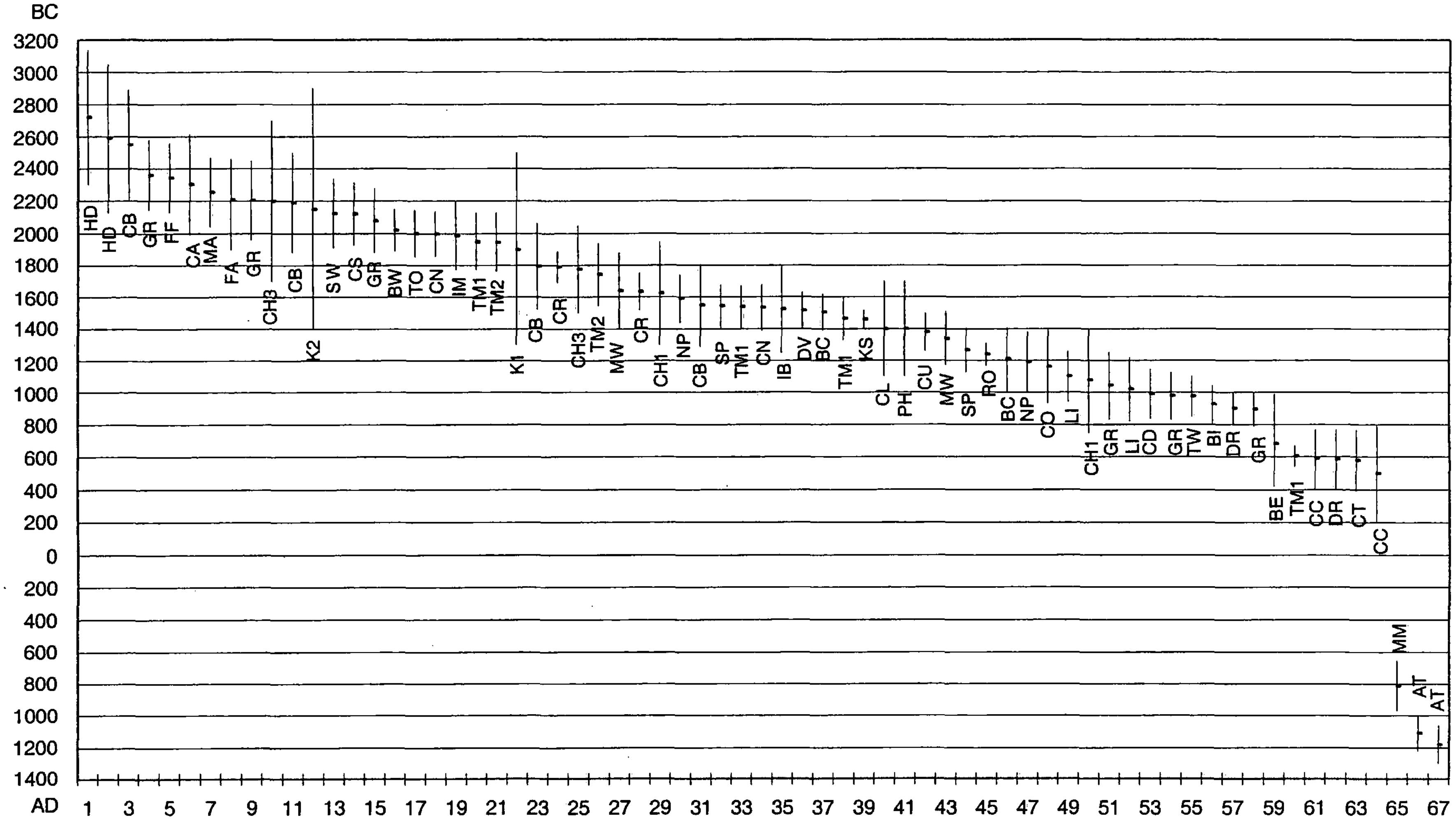


Table 3-14: Troughs, Hearths, and Other Pits by Dating Order

Site Name	Definite Troughs	Possible Troughs	Other Pits	Definite Hearths	Possible Hearths
Holme Dyke			4		
(Willington Quarry 1)	1		2	1	1
(Webbsborough 1)	1		5		
Carne B	3				
Graeanog	2	1			
Felin Fulbrook			2		
Carne A	1	2		1	
Machrie North 8	1				
Feltwell Anchor	1		6		
Clay Head III	1		5	1	1
Killeens II	2			2	
(Swales Fen)	1				
Clydesdale South	1				
Beechwood Farm	1			1	
Tougs	1			1	
Clydesdale North	1				
Island Magee	1		1		
Titlington Mt. 1	1			2	
Titlington Mt. 2	2			2	
Killeens I	1			1	
Milwich					
Clashroe	1			1	
Clay Head I	2			1	?1
Sparrowmire	1				
(Waycar)	1		1		
Imlagh Basin	1			1	
Dervaird	1				
Bryn Cefni	1			1	
Kilcor South IV	1			1	
Cob Lane	1			1	
Phillimores		2			
Curraghtarsna	1			1	
(Rhosgogh 6)		1			
(Buckenham Tofts 1)				1	
(Buckenham Tofts 2)				1	
(Phoenix Wharf)	1		2	1	
Rodway	1		1		1
Nant Porth	1				
Coarhamore	1				
(Willington Quarry 2)	1				1
Liddle 1	1			1	
(Ballyvourney I)	1			2	
(Ballyvourney II)	1			1	
(Sandy Lane)				2	

Site Name	Definite Troughs	Possible Troughs	Other Pits	Definite Hearths	Possible Hearths
Castle Donington	2		1*	2	
Tangwick	1			1	
Birstall	1				2
Drombeg	1			1	
(Ballycroghan I)	1			1	
(Ballycroghan IIa)			2	1	
(Ballycroghan IIb)	2			1	
(Ballycroghan III)	1			1	
(Deadman Bottom)	1			1	
(Bestwall)	1		1	1	
Beaquoy	1			1	
Ceann nan Clachan			1	3	
Catstown 1	1		1		
Morfa Mawr 2					
Auld Taggart 4	1			1	
(Peter Street)	1				1
Undated Sites					
Ballyhimmin	1				
Raheen	2				1
Clonkerdon	1			1	
Rathmore	1				
Castleredmond	1	2			

*This site has an unspecified number of extra pits

The Presence of Troughs, Hearths and Other Pits Over Time: The most basic characteristic of burnt mound sites, once the mound has been removed, is the trough-hearth combination. Therefore the first comparison made of burnt mound characteristics according to dating order was with the presence or absence of these two features (plus other pits, included because some of them might actually have been troughs or even hearths). This choice turned out to be serendipidous, as it produced the best indication of separate sub-groupings over time of any of the comparisons attempted. Table 3-14 shows the result of this comparison. The left-hand column contains the names for the 60 sample sites which have dating evidence, as well as a list of the 5 undated ones. The 3 sites at the end of the dated list automatically form a separate group, because they all have mediaeval dates, and would not necessarily be expected to be part of the continuous development of the earlier burnt mound type of site.

Looking at the remainder of Table 3-14, the grouping which most stands out is at the beginning of the table. This group is characterized by multiple extra pits (including some possible troughs), which only occur elsewhere in the table at a few random spots. Although 8 of the 10 sites in this group had definite troughs, only 3 had definite hearths. The multiple-pit period seems to end abruptly at around 2150 BC (judging by date range midpoints) with Clay Head III, or approximately at the time the "copper age" was ending and bronze began to appear.

The earliest group is followed by a long period, encompassing 20 sample sites from Killeens II through Cob Lane, where the most notable characteristic seems to be the definitive presence of the trough. All the sites, except one, had at least one definite trough, and 3 had two definite troughs. The one site (Milwich) which appears not to have possessed a trough, had the most minimal excavation of any of the sample sites - only straightening of the section of mound showing through a stream bank, so in this case there is a good chance that either a trough existed in the unexcavated portion or had been washed away by an expanding stream. However, the presence of hearths was still quite hit or miss in this group; 8 out of 20 sites did not seem to have one, although 3 sites had two. These sites might be called the "dominant trough group", or the "classic group", since the presence of a trough (together with the mound itself) was the feature which Brindley and Lanting (1990, 56) considered definitive for a burnt mound. This type of site continued until about 1400BC, to the end of the Early Bronze Age and a bit beyond into the Middle Bronze Age.

The next period is the least well-defined. It seems to be a transitional, or uncertain, time when perhaps the "established order" of burnt mound construction was declining and new directions were being sought. Of the 10 sites in this period from Phillimores through Willington Quarry 2, only 6 had definite troughs, while 2 others had possible troughs (in one case, 2 of them), and 2 of the sites with troughs had additional pits (in one case, 2 of them). Only 4 of the 10 sites had definite hearths, although 1 other had a possible hearth. This period continues until roughly 1100BC, close to the end of the Middle Bronze Age.

The final period of Bronze Age burnt mound activity was the time when the hearth came into its own. Of the 17 sites in this period, from Liddle 1 to Catstown 1, only 2 did not have definite hearths, and one of those did have two possible ones. Three of the sites with hearths actually had two hearths, and one other had three (although at least one of those was probably only for ordinary domestic use). This period includes the 6 most complex of the stone-walled sites described in a previous section, which in turn include 5 of the sites with the most furnace-like hearths. Most of the sites of this hearth-dominant period also had troughs; only 3 lacked at least one, and 2 sites had two troughs each. As previously mentioned, this period appears to end around 500BC.

Geographical Distribution of Burnt Mounds by Dating Order: In this and the following sections, where characteristics of burnt mound sites appear to show variation over time, they will be discussed according to the four period groupings identified above. Table 3-15 shows the geographical distribution.

Table 3-15: Geographical Distribution of Sample Sites by Period

Region	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Scotland	1	5	0	4	1
Ireland	1	6	2	8	1
England	3	7	6	5	0
Wales	4	1	2	0	1
Isle of Man	1	1	0	0	0

In the earliest (multiple-pit) period, all 5 of the separate regions with sample sites are represented, showing that even in this beginning period, burnt mounds became fairly widely distributed across the British Isles. The 3 sites in England are clustered in one section of the eastern side of the country (in Norfolk, Derbyshire, and Nottinghamshire), suggesting that that area might have been the first part of England to start creating burnt mounds, and that the ideas about them might have reached England from across the North Sea, possibly from Scandinavia, which also has large numbers of burnt mounds (Larsson 1990, 142). The 4 sites in Wales are spread along the western coast, 3 toward the south and 1 in the north, almost to Anglesey. There is also one site each in the Isle of Man and the Isle of Arran in Scotland, which, together with the Welsh sites, are all close to coasts, suggesting that the idea of burnt mounds may have reached this area by sea, perhaps from the continent, rather than across land from eastern England. Unfortunately all 5 of the undatable sample sites are in Ireland, so it is not possible to know in which periods they should belong, but only one of the dated sites from the earliest period (and it dated only by artefacts) is in Ireland. This is rather surprising, since Ireland has the largest number of known burnt mound sites of any part of the British Isles. Furthermore, the one dated site in Ireland is in County Kilkenny, toward the southeast across from Wales, and not in the southwest, where the largest concentration of Irish burnt mounds is found. This is very slim evidence on which to base a theory, but it seems possible that burnt mound ideas may have first reached Ireland via Wales, or from the same sources as Wales, which may not have been the Atlantic coastal route via Iberia and/or Brittany, from which so many of the megalithic ideas which influenced the western British Isles seem to have come. Contemporary with this earliest British burnt mound period, copper mining and processing was ongoing at Ross Island in County Kerry (in southwest Ireland), the inspiration and expertise for which O'Brien (2004, 557-60) believes reached Ireland along the Atlantic coastal route. However, O'Brien also suggests that, at the same time, copper production knowledge may have been entering Britain from the opposite direction, perhaps from central Europe (*ibid*, 560, 564-5).

In the second (dominant trough) period, 5 of the 6 dated sample sites in Ireland are in the southwest (4 in County Cork and 1 in County Kerry), the other being in Northern Ireland. By this period the Ross Island copper production centre was no longer operating, but copper ore was being mined in many small workings on and around Mt. Gabriel in County Cork (O'Brien 1994). It is not known where or how it was being processed into copper metal. This is also the principal period of mining at all the other known Bronze Age copper mines in the British Isles, except Great Orme where mining continued longer (Timberlake 2003, 26-7). In the same period burnt mound activity had spread up and down the eastern side of England from Northumberland to Suffolk, and also to the Birmingham area. In Scotland 3 sample mounds were located on the mainland in South Lanarkshire and Dumfries and Galloway – not too far from the one in the earliest period on Arran, but the other two were one each in Highland and Shetland, so in this period burnt mounds had spread all the way to the farthest northern reaches of Scotland. The one Welsh sample mound of this period was in Anglesey, and the second sample site on the Isle of Man also dates from this time.

The third (transitional) period is short compared to the others, and the few sample mounds dated to it suggest consolidation and perhaps decline. Few new areas appear and there are no sample mounds at all in Scotland. In England the only new area is Greater London, where two sample mounds were found; the other 4 were in Norfolk, Derbyshire, and the Birmingham area. One Welsh sample mound was in Anglesey and the other in Gwynedd close to Anglesey. Note that Anglesey was home to the Parys Mountain Bronze Age copper mine and was not far from Great Orme. In

Ireland the two new burnt mounds of this period were in Co. Kerry and Co. Tipperary, respectively.

In the final period of burnt mound activity in the Bronze Age and its fringes there appeared to be a new lease on life in the Scottish Isles and Ireland, and a spread to new areas in England, but with Wales out of the picture. The 4 sites in Scotland are all in the Isles (3 Northern and 1 Western) and are of the complex stone-walled type previously described. The dated sample mounds in Ireland of this period include 4 (all members of the same group) in Northern Ireland, plus one in Co. Kilkenny and 3 in Co. Cork. They include the other two of the complex stone-walled type. In England the sample mounds dated to this period are all in new areas: Leicestershire, Gloucestershire, Hampshire, and Dorset.

The 3 mediaeval-dated sample sites are found in widely separated locations, one each in southern Scotland, southern Wales, and south-central Ireland. Peter Street is dated by analogy to a nearby mediaeval house at the same stratigraphic level, but the other two have radiocarbon dates.

Mound Location Characteristics Related to Dating Order: A few of the features of the local environment of the mounds may be differentiated to some extent depending on the period in which the mounds originated. Table 3-16 shows the relationship of the type of water source to the date order.

Table 3-16: Water Sources of Sample Sites over Time (% of Sites with Known Sources)

Water Source	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Stream only	5 (50%)	9 (47%)	5 (55.5%)	7 (44%)	2 (67%)
Bog only	1 (10%)	2 (10.5%)	2 (22%)	3 (19%)	0
Stream & bog	4 (40%)	6 (31.6%)	2 (22%)	1 (6%)	0
Other	0	2 (10.5%)	0	5 (31%)	0
Unknown	0	1	1	1	1 (33%)

The mounds located beside a stream and not in boggy ground are relatively stable across all non-mediaeval periods, numbering fairly close to 50%. (It is necessary to allow wide margins because the numbers of cases in the separate groupings are so small.) Those mounds which are in bogs with no stream observed show no clear pattern, and are essentially impossible to evaluate due to the tiny numbers. Those located by a stream, as well as in boggy terrain, however, show a steady decline in percentage from earliest to latest group. And those which seemed to have some other type of water source than either a bog or a stream are only a significant group in the final stage of Bronze Age activity. As for the mediaeval mounds, Auld Taggart and Morfa Mawr are near streams, and the water source for Peter Street is unknown.

Another important environmental factor is the type of local soil, with clay apparently much the most favoured type overall. However, from the earliest to the latest BA group, there is a steady decline in the percent of sites built on clay, from 90% of the first group, through 70% and 50% for the second and third respectively, to 46% for the last.

Table 3-17: Burnt Stone Types in Sample Mounds over Time (% of Sites with Known Types)

Burnt Stone Type	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Sandstone	3 (43%)	10 (77%)	1 (20%)	5 (42%)	0
Flint	1 (14%)	1 (7.7%)	4 (80%)	3 (25%)	0
Igneous	4 (57%)	2 (15.4%)	0	2 (17%)	0
Other	2 (28%)	2 (15.4%)	0	3 (25%)	0
Unknown	3	7	5	5	3

Looking at the types of rock used to create the burnt stones found in the mounds, as shown in Table 3-17, note that the figures in the columns do not necessarily add up to 100%, because in some mounds more than one type of stone was found. The percentages of mounds using sandstone and flint vary greatly from one period to another, probably due mainly to the varying percentages of sample mounds in areas where each is a principal rock type. A surprise in this table is the igneous rock line, with over half of the earliest mounds with known types containing igneous (where the rock type is known), but few or none in other groups. In all 4 cases in the earliest group where igneous was used (3 in Wales and 1 in England), the igneous rock used was available in the immediate vicinity of the site. In the few cases from other groups where igneous was also used, it had apparently been imported from somewhere else. (In one case there was no information on this point.) These results from the stone types, the soil, and the water source collectively create the impression that the people who made the earliest burnt mounds were more concerned than were their successors to choose locations which had available the best, and in the case of water, the most, of the natural resources they would need for their operations. There could be a number of reasons for these choices. The earliest people were the pioneers in this type of endeavour, and perhaps were less confident than their successors of successful outcomes; therefore they may have chosen the optimum conditions possible to improve their chances, while later people could be more relaxed about their work. Or perhaps the technique changed around the end of the earliest period, so that it became easier to get good results even with less care given to environmental factors.

Changes in Troughs over Time: Table 3-18 shows some changes in technology which occurred in the case of troughs after the earliest period.

Table 3-18: Changes in Trough Construction over Time
(% of Sites with Troughs)

Trough Construction Material	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Pit only	5 (62.5%)	6 (31.6%)	2 (33%)	4 (28.6%)	0
Wood, Round & Planks	3 (37.5%)	8 (42%)	3 (50%)	6 (43%)	1 (50%)
Stone	1 (12.5%)	4 (21%)	1 (16.7%)	4 (28.6%)	1 (50%)
Half log	1 (12.5%)	3 (16%)	1 (16.7%)	1 (7%)	0
Stakes	0	4 (21%)	2 (33%)	3 (21.4%)	1 (50%)
Withy/Wattle	0	1 (5.3%)	0	1 (7%)	0
No trough	2	1	4	3	1

Table 3-18 is another case where the percentages in the columns do not necessarily add up to 100% because some troughs have more than one type of building material, and some sites have more than one trough. The most significant changes are a big drop in the percentage of pit-only sites after the earliest period and a corresponding increase in those made with wood and stone. In addition, stakes or pegs were not used in constructing any of the earliest period troughs, although they were used in a few cases in each of the later periods. The troughs with "washboard" bases were all from the 3rd and 4th periods. These results suggest that as time went on troughs became more and more complex. The half-log type persists in very small numbers throughout the entire BA burnt mound time span. Of the three mediaeval sites, Peter Street stands out for having a wood plank-sided trough supported by square pegs at all corners and the midpoints of the long sides, while Auld Taggart had the only trough in the entire sample which was lined with small stones.

Changes in Hearths over Time: A possible significant change in hearths over time may have happened during, or at the end of, the earliest period. The multiple extra pits which set this period apart are actually of at least two different types (and one mound dated to this time, Machrie North 8, has none of these additional pits – an exception to the rule). In some cases (Graeanog and Carne A and B), all the pits look as if they could have been troughs; i.e., they have roughly appropriate sizes and shapes, and in these cases it is probable that two or more at each site actually were troughs, but likely built in different phases of the activities at the site. This reuse of such sites may be due to the particularly favourable conditions existing at these early sites, as mentioned above. In several other cases from the same period, including some of the very earliest sites (Holme Dyke, Felin Fulbrook and perhaps Feltwell Anchor, as well as probably Willington Quarry 1 and Webbsborough, in which two cases there is little or no description of the pits), the extra (or only) pits do not look at all like troughs, and it seems barely possible that they might have represented a different type of hearth. Comparing these pits with more usual troughs and hearths, they have irregular shapes and sometimes pointed or bulbous bottoms, while troughs usually have more geometrically-identifiable shapes, flat bottoms and steep, fairly straight sides. Usual hearths are either flat on the ground surface or a slab base, or in a slight depression, while these early extra pits have depths about as great as troughs.

Enclosure of the hearth, often as simple as an arc of smallish stones, seems to have gradually but unevenly increased from the earliest to latest period. In the earliest period only 20% of sample sites had a hearth with any sort of enclosure (the extra pit-as-hearth possibility not counted in this calculation). In the second period 30% of sample sites had hearths which were to some extent enclosed, but in the third period no sample sites had any reported hearth enclosure. In the latest Bronze Age period 41% of sample sites had hearths in some way enclosed, including 5 of the 6, previously discussed, which had become almost furnaces, where the fire was mostly enclosed by walls, and possibly also by ceilings. Perhaps by the end of this period people may have discovered that if they sufficiently enclosed the fire with walls, they might not need to construct temporary coverings with stones each time they used the fireplace, which, if it happened, could account for the demise of burnt mounds after this point. The hut building at Drombeg contained a furnace-type hearth (the "roasting oven"), but there was no burnt mound around it (although there was one nearby with its own furnace-hearth).

Changes in Finds over Time: Table 3-19 shows the numbers of sample sites where artefacts were found, and the varieties found at them, for each period.

Table 3-19: Changes in Finds over Time

Find Category	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Lithics:					
No. Sites	6 (60%)	11 (55%)	8 (80%)	11 (65%)	1 (33%)
No. Types	2	7	7	12	1
Sites with Flint Flakes	50%	40%	10%	6%	0
Pottery:					
No. Sites	3 (30%)	4 (20%)	6 (60%)	7 (41%)	1 (33%)
No. Sites with Each Type	1 Peterboro 1 Beaker 1 EBA	1 Beaker 1 EBA-MBA 2 undiag.	1 Beaker 2 MBA 1 BA-IA 1 BA-E.Hist 1 post-D.-R & LBA.	1 Beaker, but mostly LBA 1Dev.-Rim 5 undiag.	1 Med. Ceramic
Fired Clay Pcs.	1 site	1 site	0	1 site	0
Bone:					
No. Sites	3 (30%)	6 (30%)	3 (30%)	4 (23.5%)	1 (33%)
Metallurgical:					
No. Sites	0	2 (10%)	1 (10%)	1 (6%)	0
Types Objects		1 gold ring 1 bronze pc. & ore	slag	2 copper bracelets (also clay mould)*	0

*listed under Fired Clay Pcs.

On the whole, it seems there was surprisingly little change over time in the artefacts found. Lithics were found at more than 50% of sites in all BA periods, and the percentages show no clear trend across the time span. The types of artefacts found do tend to increase from early to late, however. For example, at sites from the earliest period, the only stone artefacts found were flint flakes and flat stones which might have been used for crushing or grinding; while in the final period, in addition to those, there were pounders, pot lids, ard shares, worked flint, quartz pieces, querns, whetstones, rubbers, a spindle whorl and a shale bracelet. On the other hand, the percentage of sites with flint flake finds steadily and steeply decreases across the centuries, which might indicate that flint was in the process of becoming obsolete as metal replacements for flint tools and weapons became increasingly available.

The percentage of sites where pottery was found is somewhat greater in the two later BA periods than in the earlier ones, but there is no very clear trend. However, the 3 sites with unusually large numbers of potsherds (previously mentioned) are all from the latest BA period. From the types of pottery identified, it can be seen that the period indicated by the potsherds does not always correspond to the site's radiocarbon dating – Beaker sherds are found in all BA periods!

The percentage of sites with bone also remains quite stable across the entire BA time span, with only a bit of a dip at the end, probably insignificant in view of the very small numbers involved. Every period after the first shows some evidence of metal products or production processes, but the number of such sites is extremely small throughout.

Of the mediaeval-dated sites, only one (Peter Street) produced any artefacts; it had lithics and pottery in the form of 4 mortars (3 stone and 1 ceramic), and animal and fish bones.

Changes in Surrounding Features over Time: The percentages of sites with post- or stakeholes, excepting those within troughs, also remains quite stable across the Bronze Age time span (40%, 30%, 40%, and 59% from earliest to latest) until the final period, where the increase is one more indication of the greater complexity of the sites at that time. Furthermore, the final period has 2 sites with two separate groupings of post- or stakeholes and one site with three such groupings; the only other site with more than one grouping is Graeanog, listed in the earliest group due to its early phase, but which has another phase about a thousand years later to which one of its groupings belongs. The mediaeval sites have no stake- or postholes outside of troughs.

Table 3-20 shows the numbers and percentages of sample sites which are known to have other, broadly contemporary, sites nearby (within 10 km) in each period.

In all periods the majority of sample sites have other burnt mounds not far away, but there seems to be some decrease after the earliest period, possibly due to the spread of the burnt mound concept to more and more areas, some of which may have had less favourable conditions and therefore attracted the establishment of fewer burnt mound operations. Domestic sites near sample burnt mounds are fairly few in all periods and there is no very clear trend. Nearby ritual sites are probably the most surprising aspect of this table; not only is the percentage of sample sites near them significantly largest for the earliest period, but also the numbers of ritual places near individual sample sites is greater in this period than in others. Perhaps a belief that supernatural forces determined what happened at burnt mound sites was strongest at the outset. Over time burnt mound operations may have come to seem more mundane, or less in need of supernatural help. Other types of sites than those already mentioned seem to increase with time near sample sites, possibly a result of the spread of burnt mounds to new areas, or of population or technological expansion.

Table 3-20: Changes in Nearby Sites over Time (by Numbers of Sample Sites)

Type of Near Sites	1st Period	2nd Period	3rd Period	4th Period	Mediaeval
Other burnt mounds	10 (100%)	16 (80%)	6 (60%)	12 (71%)	2 (67%)
Domestic	1 (10%)	4 (20%)	1 (10%)	4 (23%)	1 (33%)
Ritual	7 (70%)	5 (25%)	1 (10%)	3 (18%)	0
Other	1 (10%) flint scatter	4 (20%) 3 field systems 1 gold hoard & flint scat.	4 (40%) 1 mine 1 weapons hoard 1 ring fort 1 cursus, henge, & ring ditch	6 (35%) 4 weapons hoard (all same b.m. group) 1-2 hillforts 1 flint scat.	0

Two of the three mediaeval mounds had other burnt mounds nearby, not including Peter Street, which was the only one with a close domestic site, and no additional near sites were reported for these mounds. From all the various items of data concerning the three mediaeval-dated mounds, Peter Street is the one which most stands apart from the other two, and seems most likely to be truly a mediaeval creation, but with no guarantee it was used for the same purpose as the basically Bronze Age sites. Peter Street's carefully crafted and relatively well-preserved trough, in particular, appeared likely to date from a later period than the others. In contrast, each of the other two mediaeval-dated mounds was part of a group of burnt mounds. In the case of Auld Taggart, three of the four other dated mounds in its group had Bronze Age dates (only its nearest neighbour sharing its mediaeval dating); however, it does have the trough lined with small stones, unlike any at sample Bronze Age sites. Morfa Mawr, on the other hand, was a burnt stone heap with no discernible trough or hearth, and so could be simply a dump of extra waste material from a neighbouring, operational, burnt mound site. Unfortunately, less than half of this mound was excavated, so we cannot be sure that a trough and/or hearth were not present, and no other mounds of its group were radiocarbon-dated.

Conclusions

What has been learnt about the nature of burnt mounds through the study described in this chapter? The general results have broadly confirmed much that was already known: the usual location close to a stream; the usual presence of at least one trough; and, somewhat less often, at least one hearth; and usually a Bronze Age date. The details of these features have been clarified to some extent. The trough is most often rectangular, with an average length-to-width ratio of 1.5 to 1, and the width most often about 1m; whether the trough is rectangular or oval depending mainly upon the presence or absence of a wood or stone structure inside. The hearth is most often a sub-circular single spot about 1m in diameter. The date range of burnt mounds is continuous throughout the Bronze Age, but appears to begin toward the end of the Late Neolithic and extend into the Early Iron Age, with a few mounds having mediaeval dates.

Some common assumptions about burnt mounds have been challenged. A surprisingly large proportion of excavated sites have produced finds of lithic tools and pottery; even bones are not as uncommon as previously thought. While only a minority of burnt mounds are near ritual or domestic sites, most are close to other burnt mounds.

The study of changes in burnt mound characteristics over time has produced more new information. On the basis of features found under the mound over time, burnt mounds seem to divide into four period groupings which happen to roughly correspond to the periods which have long been used to divide the Bronze Age: the "copper age" (before the addition of tin to make bronze), then the Early, Middle, and Late Bronze Ages. Does this correspondence have any significance, or is it purely coincidental? If not coincidental, do the changes in burnt mounds merely reflect other changes in society as seen through types of artefacts and monuments, for example, which have determined the traditional division of the Bronze Age? Or could burnt mounds be a part of the cause which has brought about the changes on which the traditional division is based? These are fundamental questions to which there are at present no answers.

The burnt mounds of the earliest grouping often have a series of extra pits, in addition to (usually) a trough, suggesting a possible difference in function or technology from those that followed; those of the second group have lost the extra pits, but very definitively possess at least one trough; the third group seems indefinite about both troughs and hearths; and the fourth group especially features the hearth, which in several cases has developed into a kind of intermediate stage between a simple hearth and a furnace. In general, changes in burnt mound site features from earliest to latest are in the direction of greater complexity, and in the case of artefacts, more of them and more different types, except for flint knappings, which are in the process of disappearing.

Except for the possible metallurgical uses of the stream, trough and hearth, as outlined in Chapter 2, material evidence for use of burnt mound sites for copper production is almost totally lacking. Two sites in the vicinity of known copper sources produced a small amount of copper, ore, and slag, and one other site had a clay mould fragment, but otherwise specifically metallurgical material was completely lacking. Even such possible tools as pounding stones and flat stone surfaces were only found at a small minority of sites.

Chapter 4

XRF ANALYSIS OF BURNT MOUND MATERIAL

To help determine whether burnt mounds were metal-processing sites, a method was sought which could identify any traces of copper and/or tin present in materials found at burnt mound sites, even though these metals might be disguised in compound form and in minute particles not identifiable with the naked eye. After consideration of various methodologies, a decision was made to collect samples of mound material from several burnt mounds and subject them to XRF (x-ray fluorescence) analysis. This technique was used for a geochemical survey of Great Orme in 1997, where it produced high readings for copper concentrations in the soil of known mining areas, and also at two suspected prehistoric ore washing sites and one possible Bronze Age smelting place (Jenkins *et al.* 2001, 164-9). XRF was also used in a similar survey at Alderley Edge, where most of the known mine workings and processing places were identified by higher-than-normal copper readings, and some other copper "hot spots" were noted for future investigation as possible ancient processing sites (Timberlake and Prag 2005, 223-4, 228). In both of these cases, a portable field analyzer, which can take readings of concentrations of various metallic elements simply by laying a probe directly on the ground surface, was used. In a trial run with a stationary XRF analyser, slight positive readings were obtained for both copper and tin from three burnt stones picked up at random from burnt mounds in the Yorkshire Dales, which further influenced the decision to use this method.

Site Selection

A group of three unexcavated burnt mounds, located at Sturdy Springs in Teesdale, was selected for extraction of samples to be analysed. This site is about 5km west of Middleton Tyas, a copper mining centre in the 18th and 19th centuries (Hornshaw 1975), and is only about 1km from the nearest of the mine workings of that period (T. Laurie, pers. comm.). Also, a copper mill and a buddle house (for concentrating ore) once existed less than 1km from the triple burnt mound site (ASDU 2007, Figure 1), so copper has been processed as well as mined nearby at least during the modern era, although no evidence of Bronze Age mining has yet been reported from this area (Timberlake 2003, 37).

Sample Collection

On each of the three Sturdy Springs mounds, a tape measure was laid over the mound, extending in each direction several meters beyond the mound in order to provide a base line for local soil metal content. Then, at 1-meter intervals along the tape line, the turf was lifted and a trowelful of soil or mound material dug out, bagged, and labelled. Figure 4-1 shows the plan of the 3-mound site, including the approximate lengths and positions of the lines along which the samples were collected. Due to the positions of a number of gorse bushes growing on the mounds, which would have been difficult to dislodge, in all three cases the clearest path for the series of samples was over the middle of the mound from back to front, then through the stream which all the mounds faced, and ending at the opposite bank.

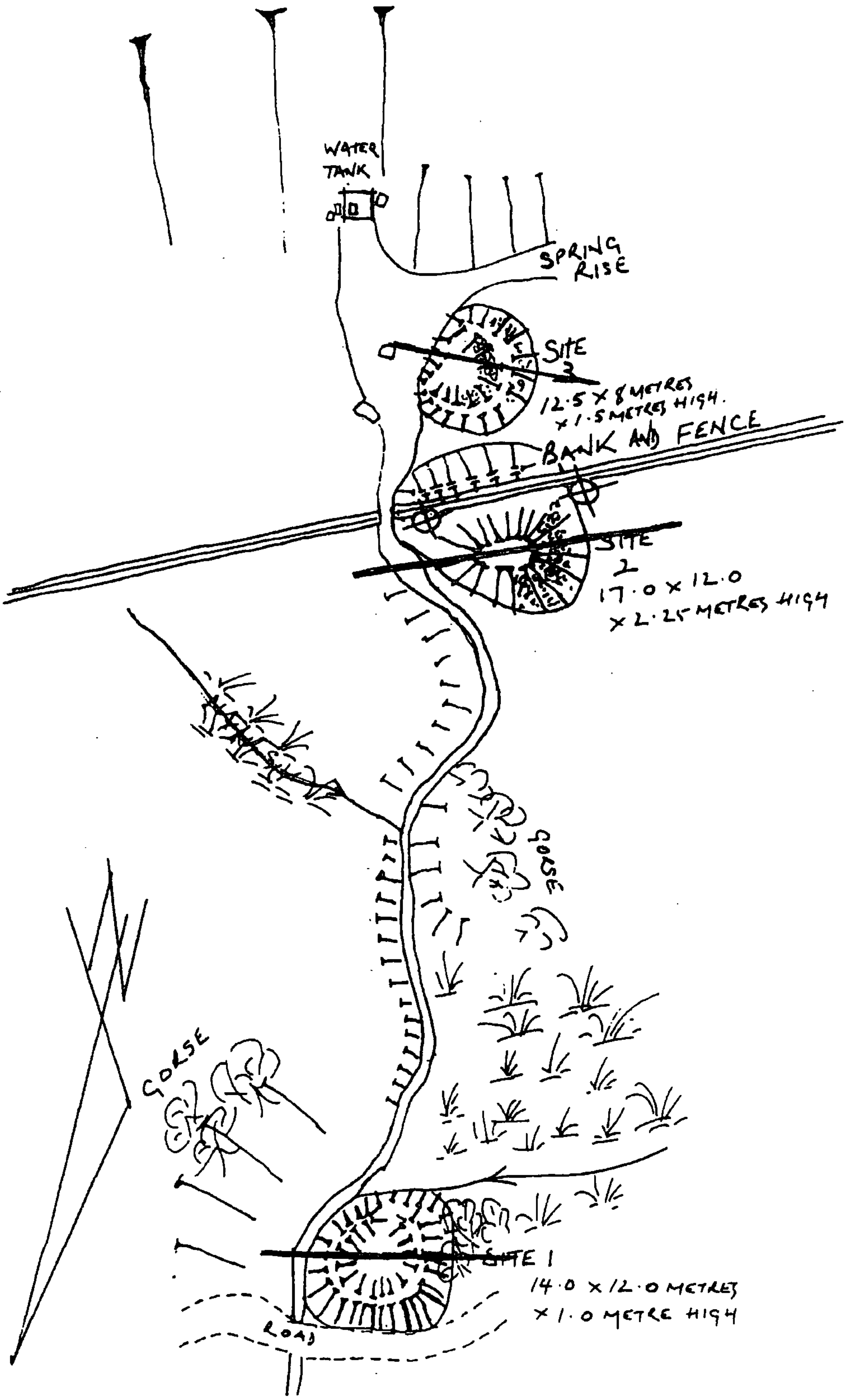
Radiocarbon Date

From the mound labelled Site 3 on the plan (see Figure 4-1), a few small pieces of charcoal were extracted along with the soil and were retained for radiocarbon dating. Charlotte O'Brien, Archaeological Services Durham University staff member, selected an appropriate piece of the charcoal for dating and determined that its species type was hazel. This was sent to the Beta Analytical Radiocarbon Dating Laboratory, where it became sample number Beta-213524 and produced a date range of 3810±40 BP, or Cal BC 2400-2380 and Cal BC 2360-2140 at 2 sigma (95% probability) and Cal BC 2300-2200 at 1 sigma (68% probability). This date range places Sturdy Springs #3 in the earliest group of burnt mounds, according to the time divisions established in Chapter 3. In this "copper age" date range tin would not be expected to be present to any significant extent, even if the site was used for metal production.

EDXRF Analysis

The soil samples from the three mounds, which had been air-dried for several weeks, were each sieved to remove particles larger than 2mm, then ground to a fine powder. A portion of each sample weighing 0.5g was then pressed into a 13mm diameter pellet at 15 tonnes pressure. The analyses were undertaken on an Oxford Instruments ED2000 Energy Dispersive X-ray Fluorescence (EDXRF) spectrometer (P. Clogg, pers. comm.). XRF "operates through the bombardment of a sample with

Figure 4-1: STURDY SPRINGS BURNT MOUND SITE
Whashton C.P., Teesdale
NZ 135 052 258m OD



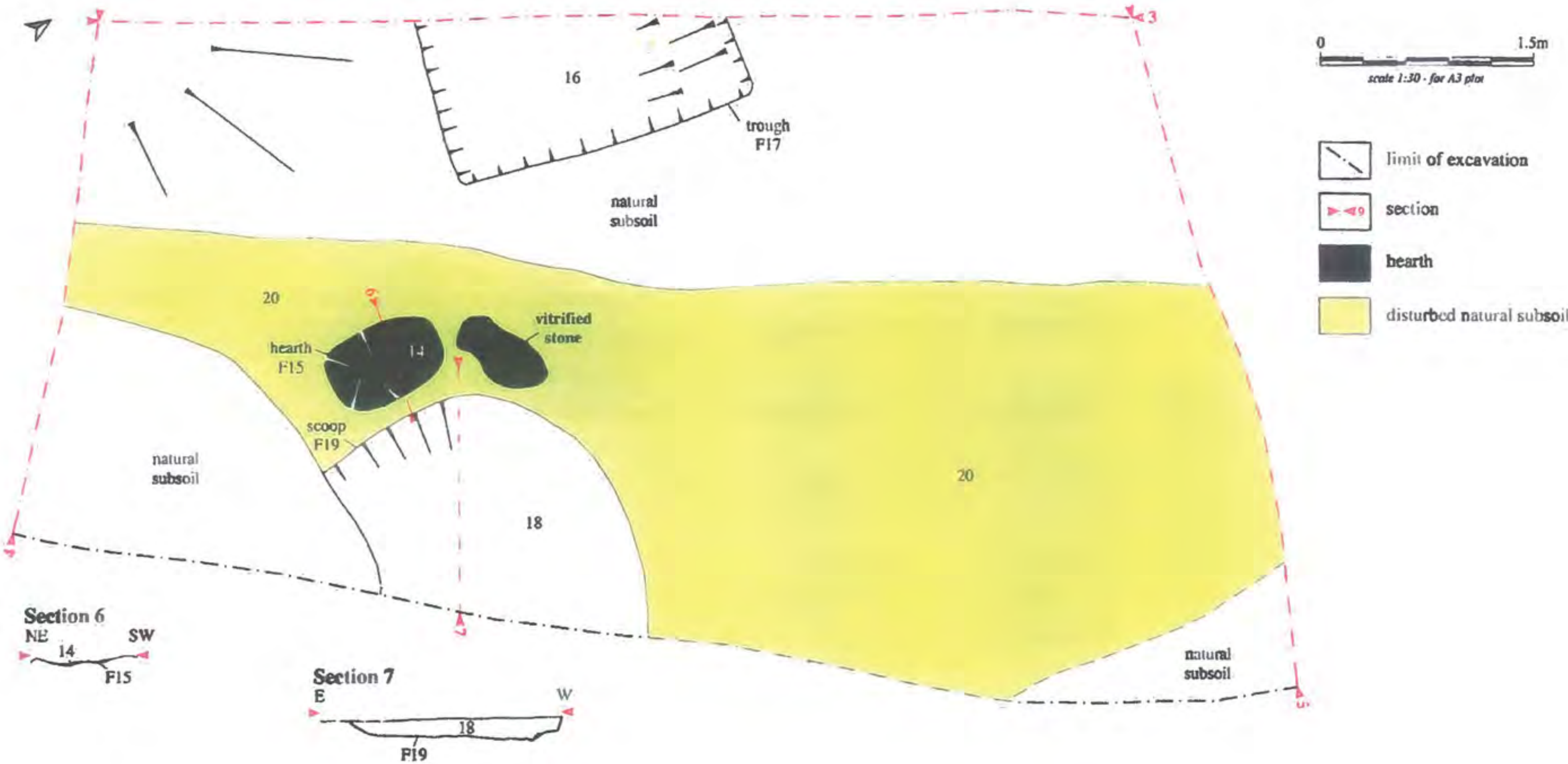
Drawing by Timothy Laurie

high-energy x-rays which excite secondary fluorescent x-rays whose wavelengths/energy levels are characteristic of the elements present and whose intensities relate to the concentrations of those elements" (Jenkins *et al.*2001, 164-5). There are two types of XRF systems: energy dispersive (EDXRF), where "the secondary x-ray emitted by the excited atom within the sample is considered to be a particle, whose energy is characteristic of the atom from whence it came"; and wavelength dispersive (WDXRF), where "the secondary x-rays are regarded as being electromagnetic waves, whose wavelength is characteristic of the atom from whence they came" (Pollard and Heron 1996, 41-9). In the EDXRF instrument, electrical energy is used to excite the atoms of the various elements in the sample, and the energy which they in turn produce is measured and recorded. The results of this process were presented as output from the analyser in the form of lists of elements with their respective concentrations in each sample given in parts per million (ppm) or weight %, depending on the amount present. The analyses were carried out by Phil Clogg, Durham University Archaeology Department.

Excavation of Sturdy Springs #1

The ground on which the group of three sampled burnt mounds lie is owned by the Crown, and is used by the British Army as a firing range. After the above-described samples were collected, the Army financed an excavation of one of the three mounds, with the Archaeological Services unit of Durham University (ASDU) contracted to carry out the work. Sturdy Springs #1 was selected for excavation, as it appeared to be the least disturbed of the three. The half of this mound facing the stream was excavated by a team headed by Jason Mole during a 2-week period in October 2006. After the turf was taken off by machine, topsoil 0.05m deep and silt with a maximum depth of 0.46m (J. Mole, pers. comm.) was removed before the probable top of the ancient burnt mound was reached. The excavation eventually unearthed a self-filling rectangular trough, 2.2m long, 1.08m wide and 0.36m deep, cut into a patch of yellow clay, and filled with light grey clay silt. Lipid analysis was carried out on a sample of the trough deposit, but produced no evidence of animal fat and only traces of plant leaf waxes. A sub-oval hearth, measuring 0.8m long and 0.58m wide, was found, unusually, between the trough and the stream. Beneath it the ground had been "altered to a depth of 0.17m by successive episodes of burning,

Figure 4-2: Plan of Sturdy Springs #1 Excavated Area



Source: Archaeological Services Durham University Report 1569

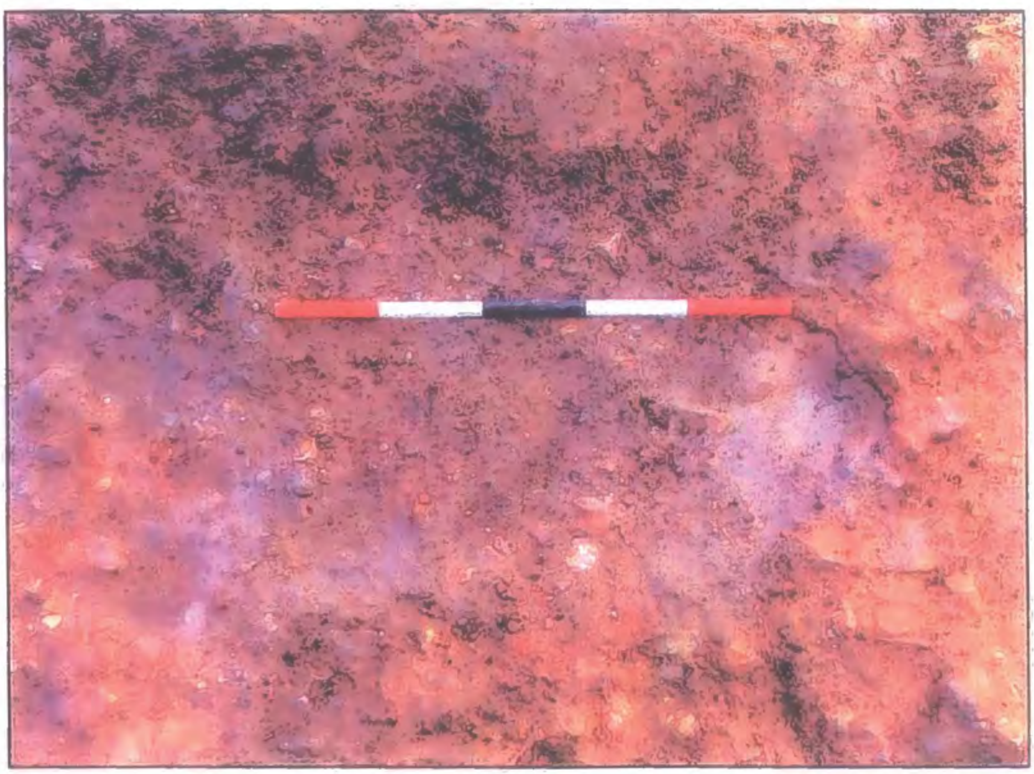
Figure 4-3: Northwest facing plan shot of mound showing build-up of silt

Figure 4-4: North facing shot of mound showing north and south horn and slumped material

Source: Archaeological Services Durham University Report 1569

Figure 4-5: Northeast facing shot of trough

Figure 4-6: Southwest facing shot of hearth



Source: Archaeological Services Durham University Report 1569

leaving a compacted laminated red-orange crust of burnt, almost vitrified, sand and sandstone, with small flecks of charcoal" (ASDU 2007, 4). A mass of vitrified stone was found beside the hearth. Vitrification may start at around 700-800°C, but normally occurs at about 1000°C (C. Caple, pers. comm.), so the presence of vitrified stone gives a general idea of the temperature reached in the hearth. A plan from the excavation report showing the positions of these features is included as Figure 4-2 (ASDU 2007, Figure 4), as well as pictures showing the excavation in progress, including the trough and hearth, as Figures 4-3 through 4-6 (*ibid*, Figures 8-11). A radiocarbon date of 1430-1260 Cal BC (98% confidence) was obtained from charcoal in the hearth (*ibid*, 4).

The excavation team saved soil samples from most contexts found within the mound, and sub-samples of these were obtained, pelletised, and analysed by Phil Clogg using EDXRF. Unfortunately, no samples were taken from the hearth material, the trough itself, or the old ground surface, and the lower contexts of the mound are less well represented than the upper ones. The results of the analysis are described below, following those from the earlier samples.

Results from Over-the-Mound Sampling

The results are shown in the form of graphs of the concentration of single elements, in each case moving from sample to sample at the 1-meter intervals starting behind a mound, crossing over it, then finishing beyond the stream (Figures 4-7a – 4-9i). In cases where a particular point does not appear on a graph, it is either because the sample could not be made into a pellet for analysis, or because the concentration of a particular element was less than the minimum detection level. (P.Clogg, pers. comm.). Metals are normally detected in soils, so only if the concentrations are considerably larger than what would normally be expected can they be judged to be significant anomalies. For example, the world crustal average concentrations for the elements of particular interest are: copper – 55 ppm, lead – 1.3 ppm, zinc – 70 ppm, tin – 2 ppm, nickel – 75 ppm, arsenic – 1.8 ppm, and titanium – 4400 ppm (Timberlake and Prag 2005, 225). Also, evidence of high concentrations of metals could result from unusually large amounts of those elements present naturally in the local geology, or from modern metal production nearby, or from metal objects corroding in the soil. Comparing the graphs with each other, several trends can be noted, and are described below.

Figure 4-7a: SS#1 Topsoil Copper Concentrations

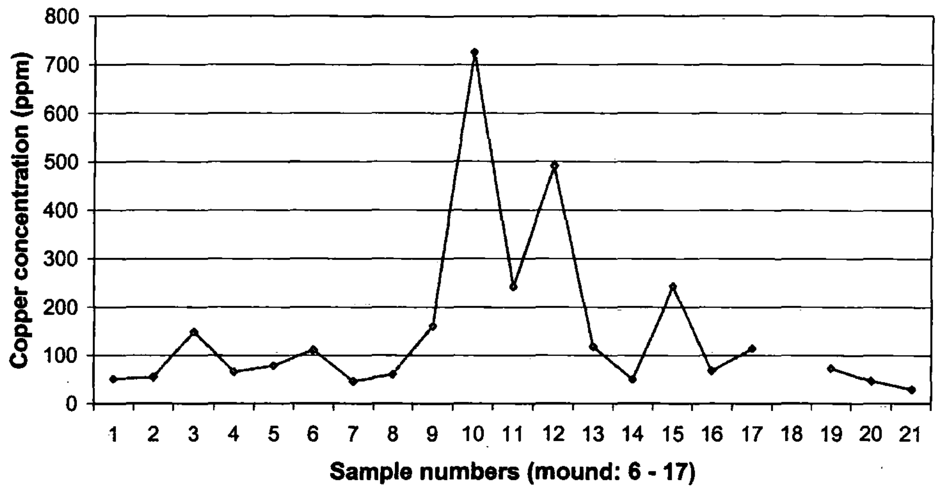


Figure 4-7b: SS#1 Topsoil Lead Concentrations

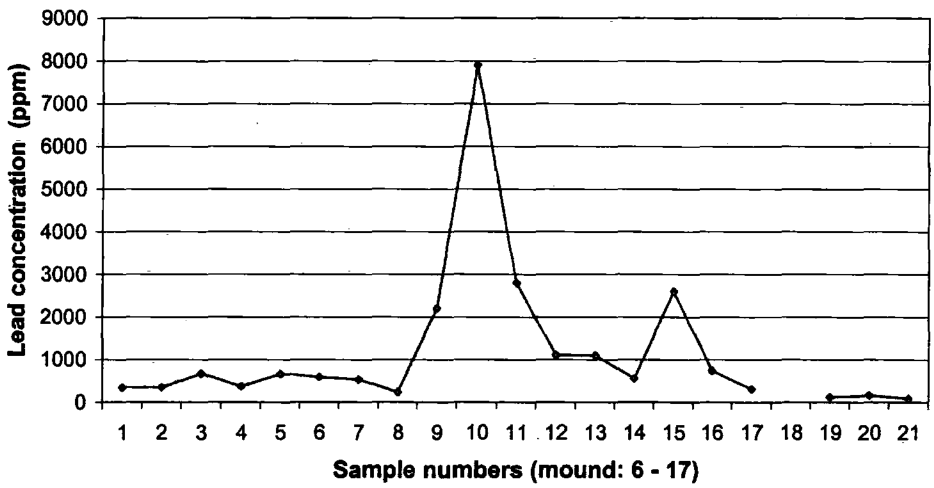


Figure 4-7c: SS#1 Topsoil Zinc Concentrations

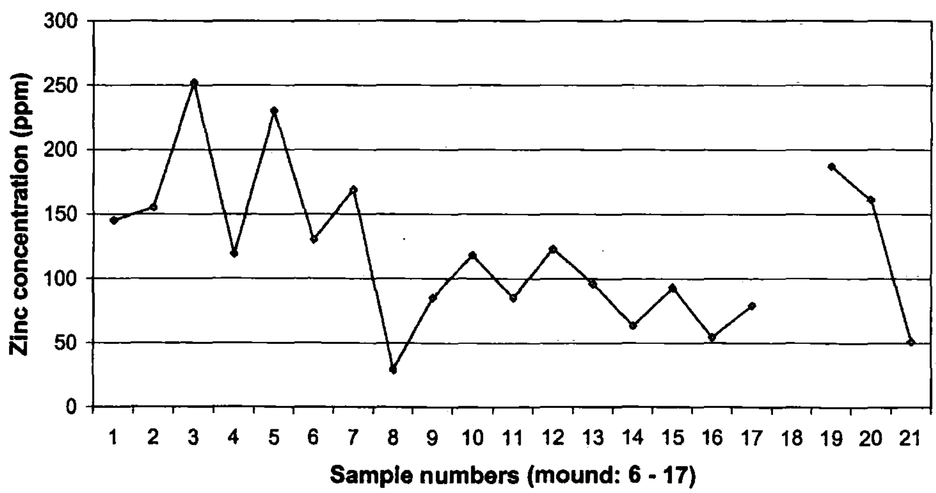


Figure 4-7d: SS#1 Topsoil Nickel Concentrations

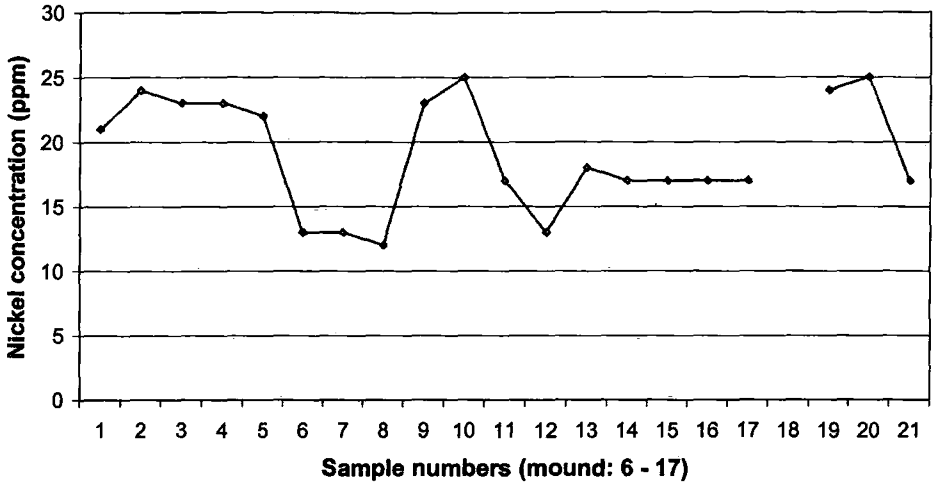


Figure 4-7e: SS#1 Topsoil Phosphorus Concentrations

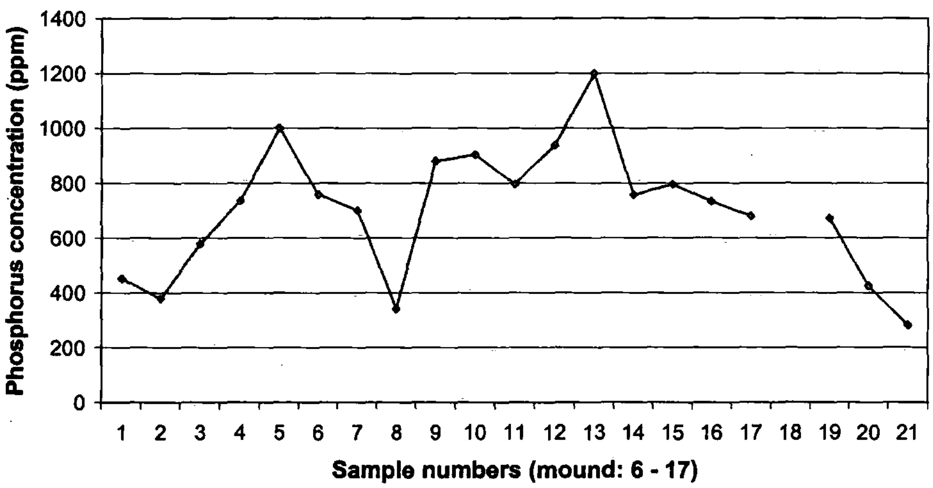


Figure 4-7f: SS#1 Topsoil Arsenic Concentrations

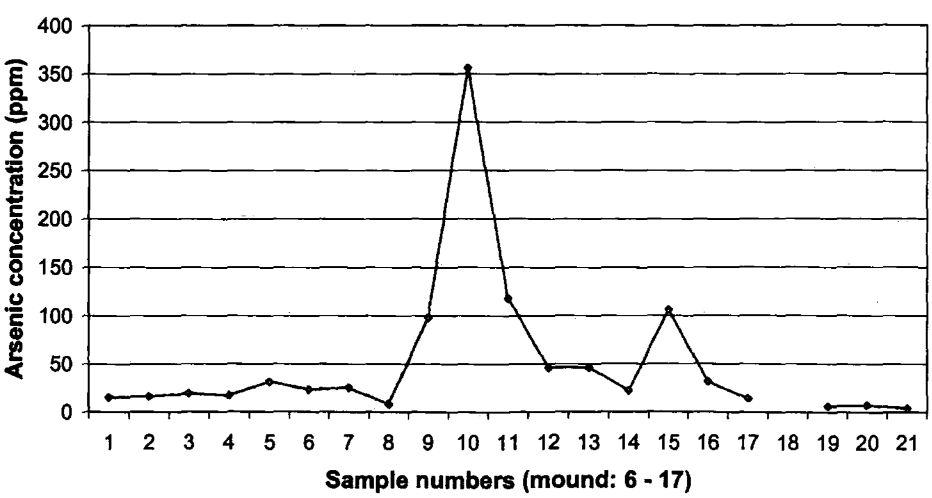


Figure 4-7g: SS#1 Topsoil Titanium Concentrations

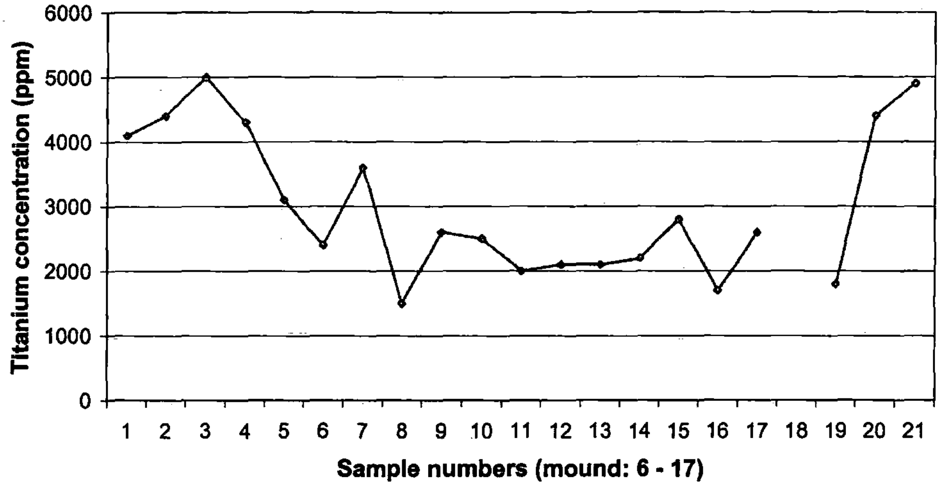


Figure 4-7h: SS#1 Topsoil Sulphur Concentrations

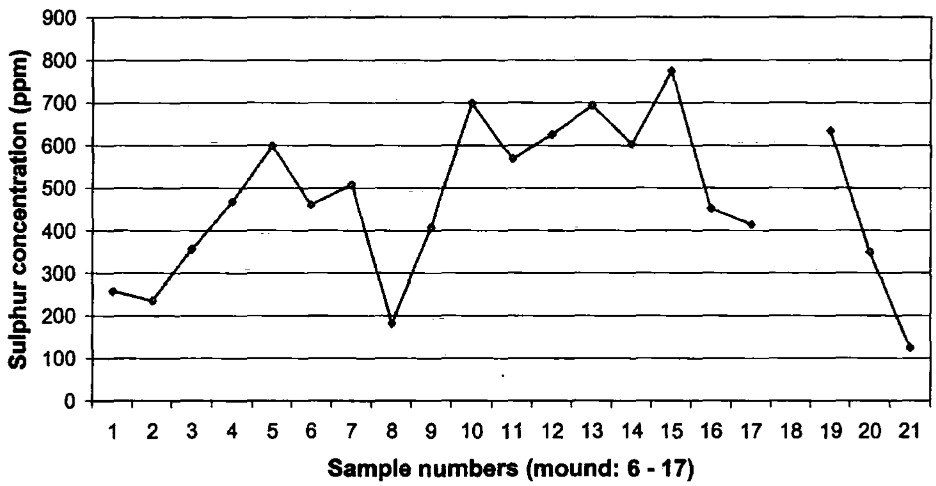


Figure 4-8a: SS#2 Topsoil Copper Concentrations

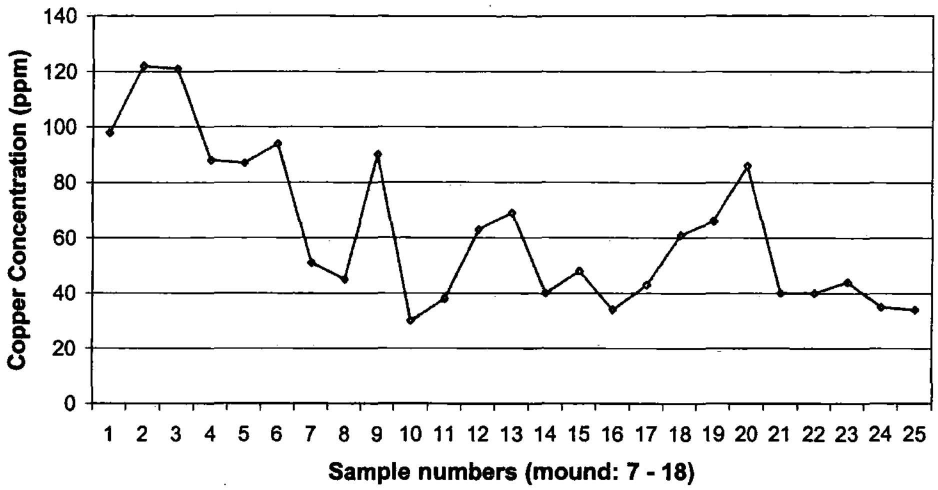


Figure 4-8b: SS#2 Topsoil Lead Concentrations

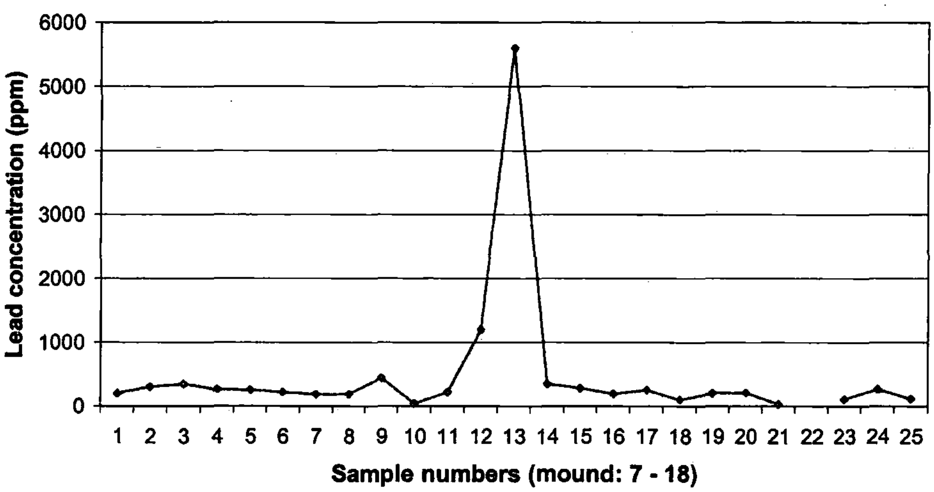


Figure 4-8c: SS#2 Topsoil Zinc Concentrations

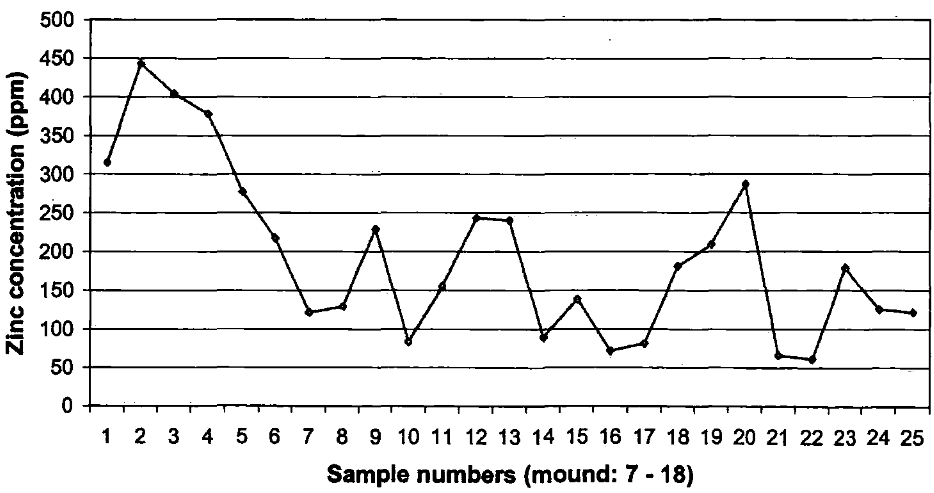


Figure 4-8d: SS#2 Topsoil Nickel Concentrations

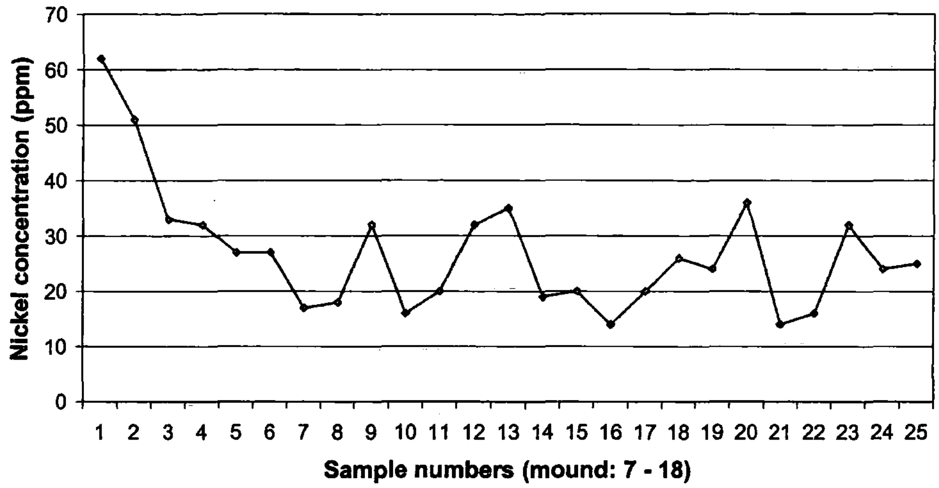


Figure 4-8e: SS#2 Topsoil Phosphorus Concentrations

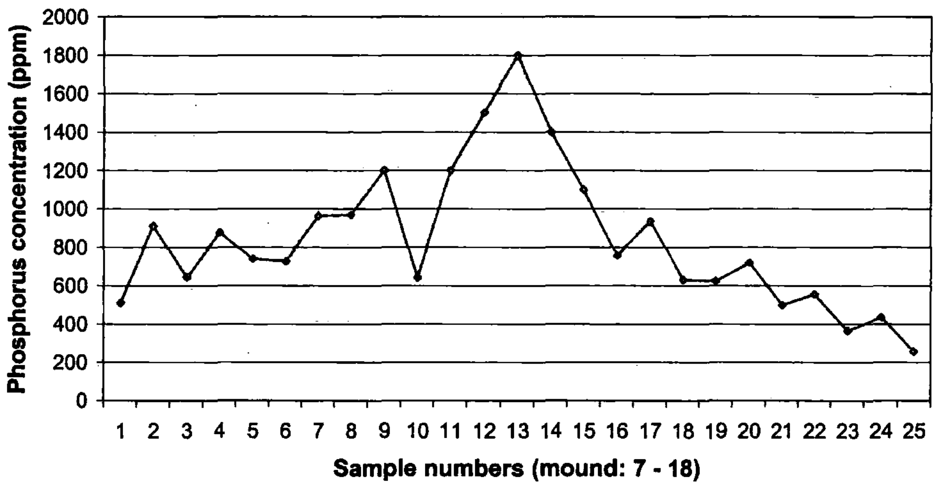


Figure 4-8f: SS#2 Topsoil Arsenic Concentrations

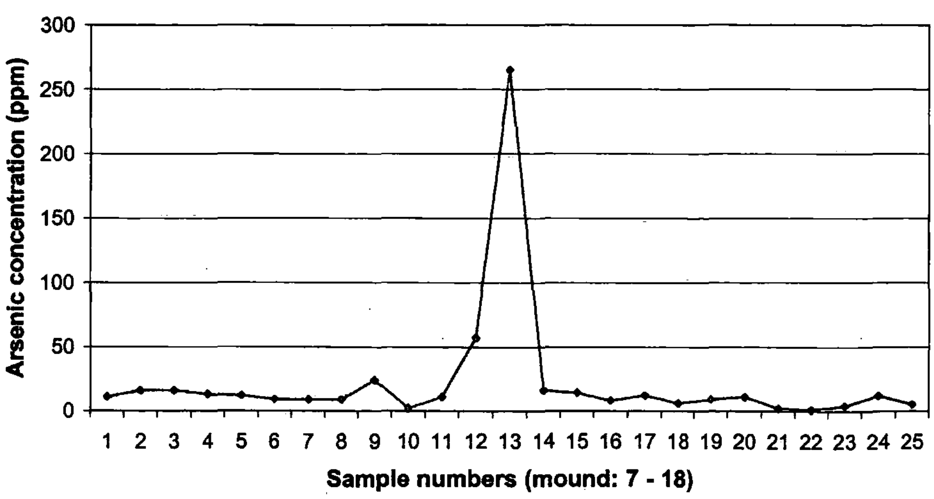


Figure 4-8g: SS#2 Topsoil Titanium Concentrations

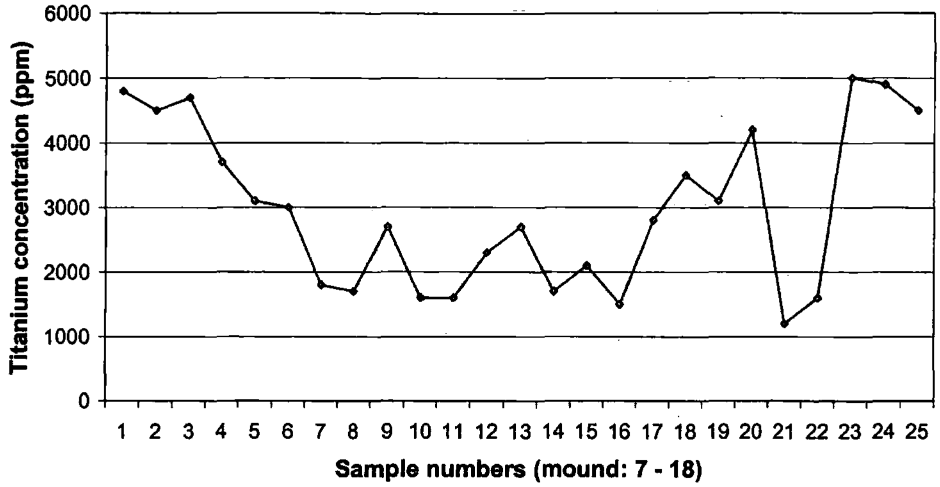


Figure 4-8h: SS#2 Topsoil Sulphur Concentrations

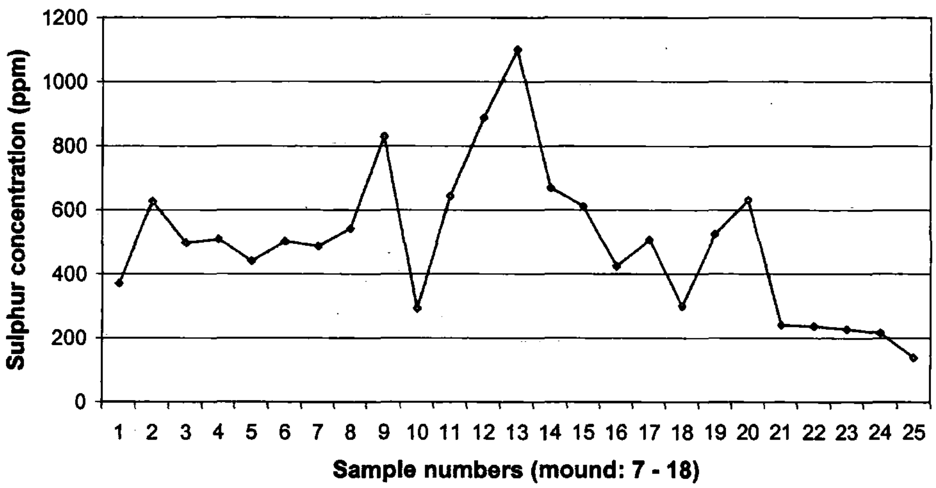


Figure 4-8i: SS#2 Topsoil Chlorine Concentrations

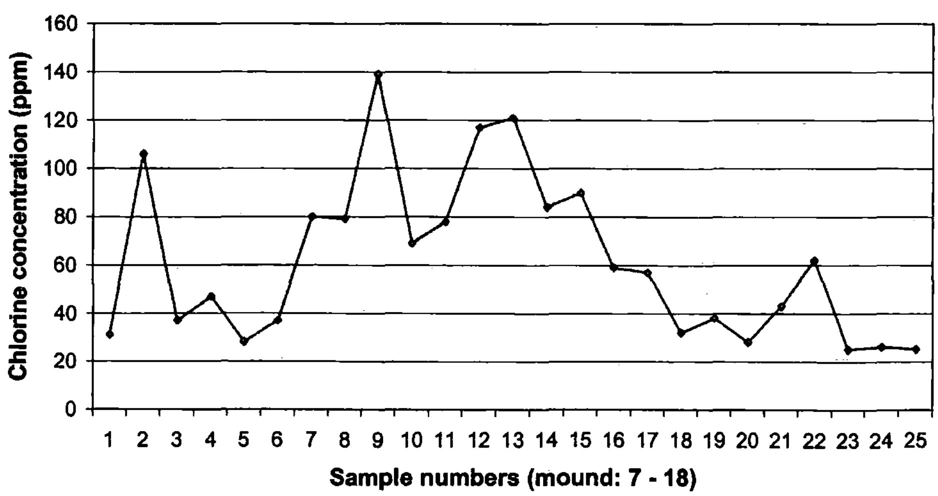


Figure 4-9a: SS#3 Topsoil Copper Concentrations

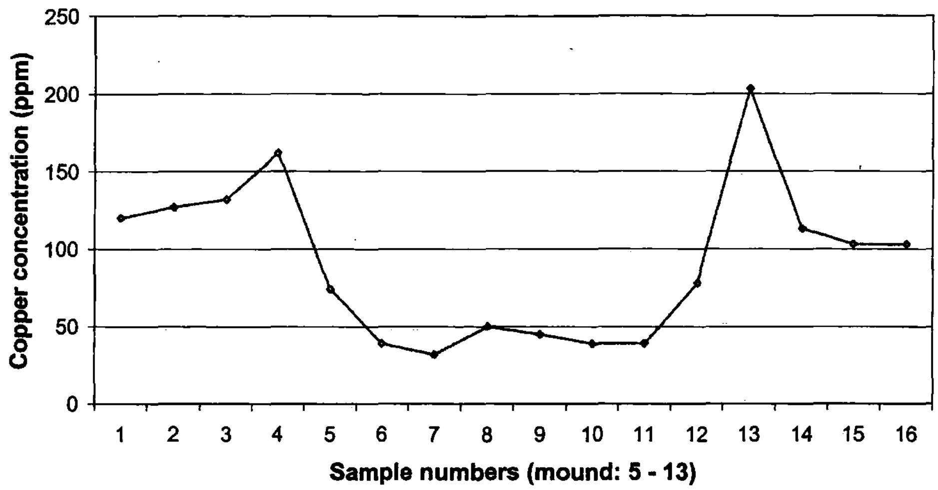


Figure 4-9b: SS#3 Topsoil Lead Concentrations

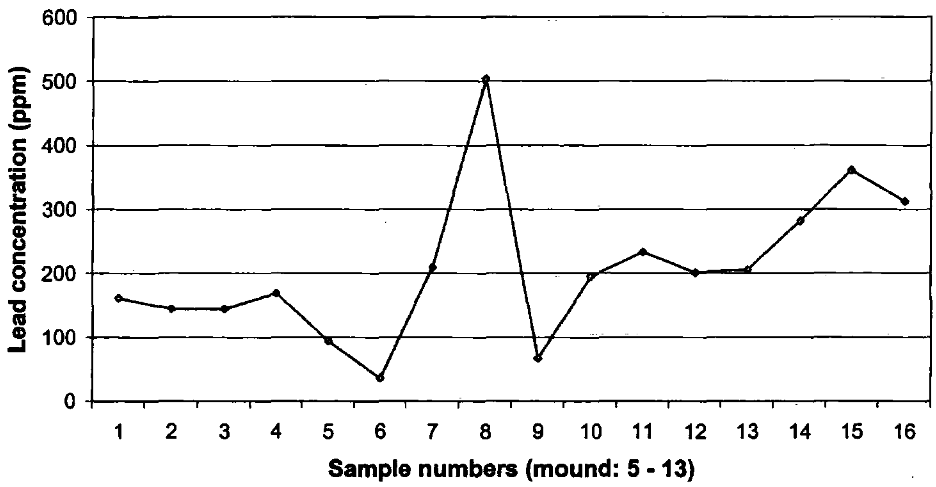


Figure 4-9c: SS#3 Topsoil Zinc Concentrations

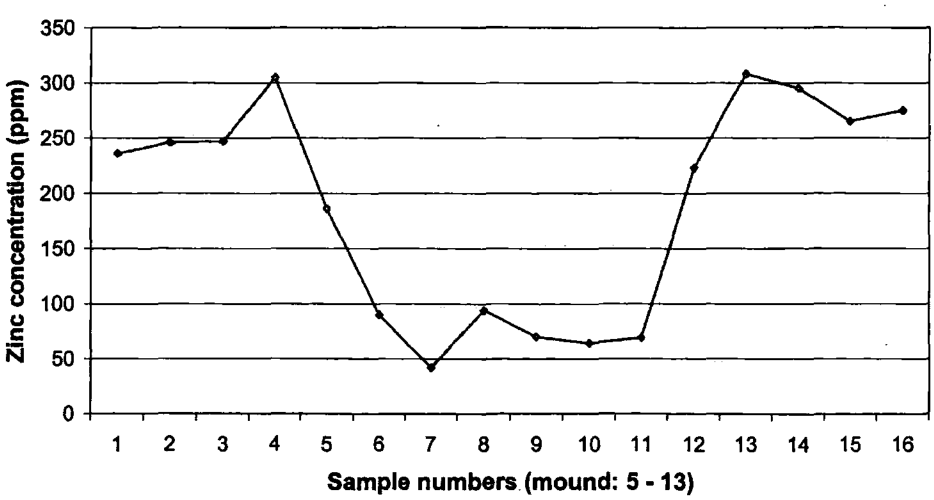


Figure 4-9d: SS#3 Topsoil Nickel Concentrations

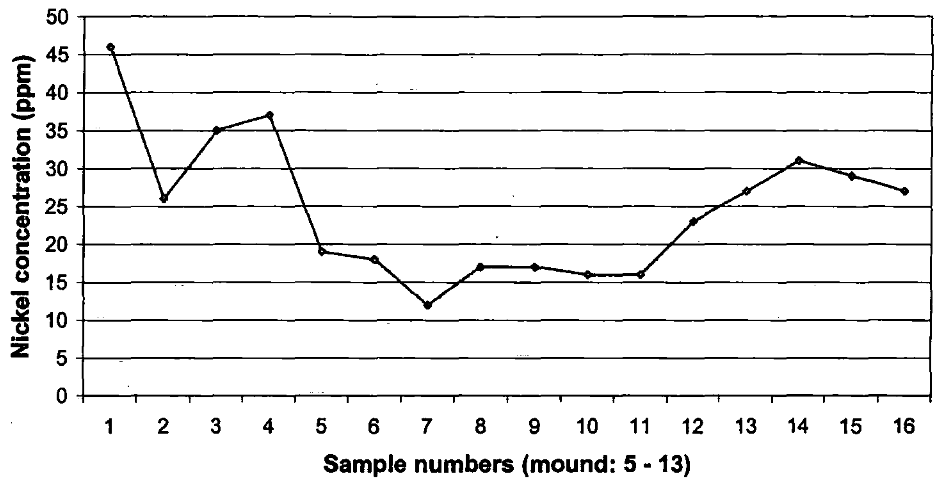


Figure 4-9e: SS#3 Topsoil Phosphorus Concentrations

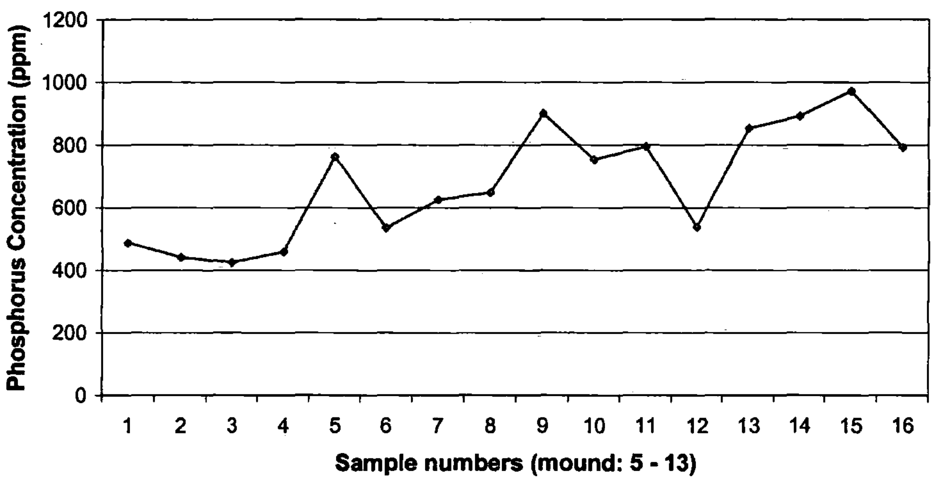


Figure 4-9f: SS#3 Topsoil Arsenic Concentrations

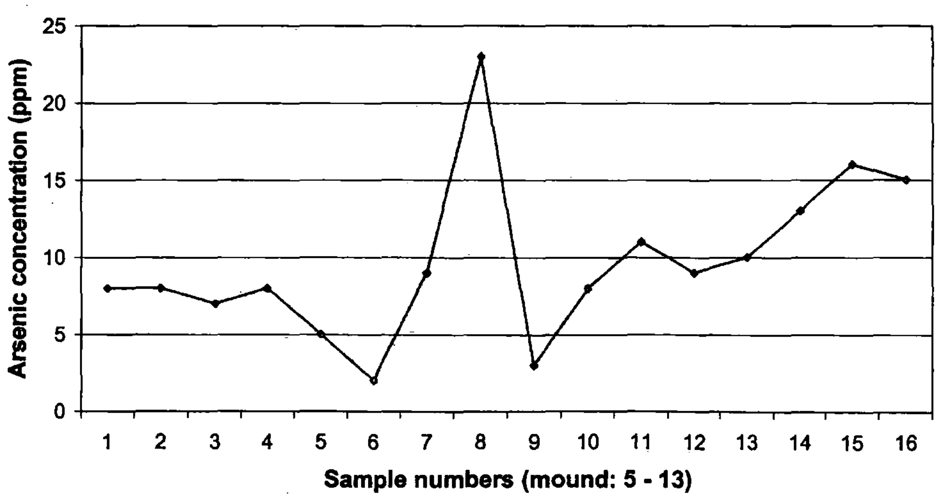


Figure 4-9g: SS#3 Topsoil Titanium Concentrations

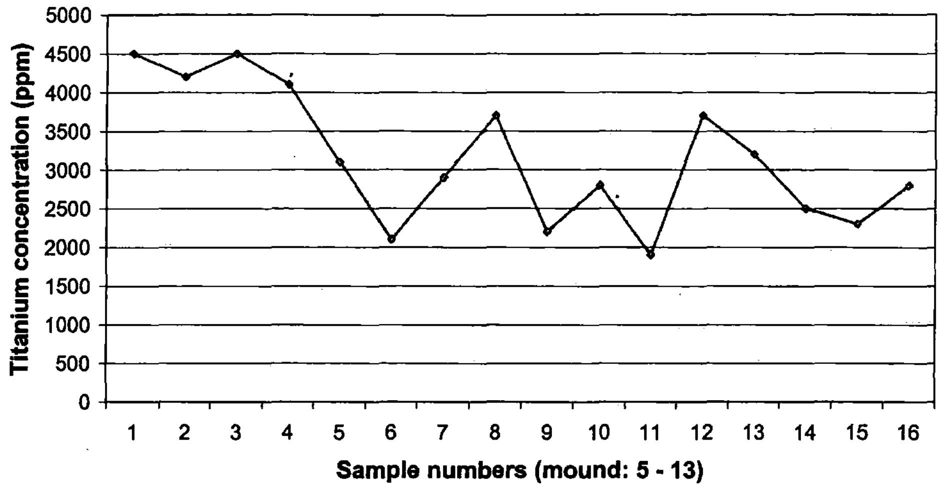


Figure 4-9h: SS#3 Topsoil Sulphur Concentrations

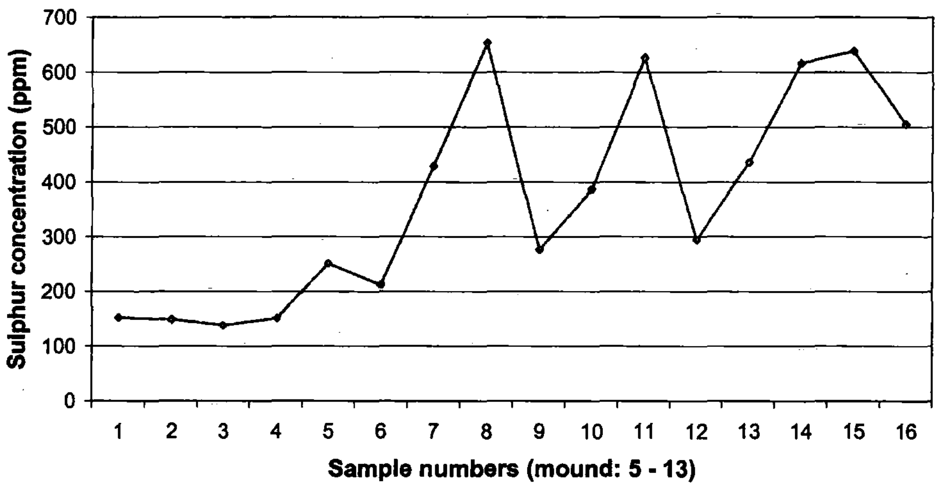
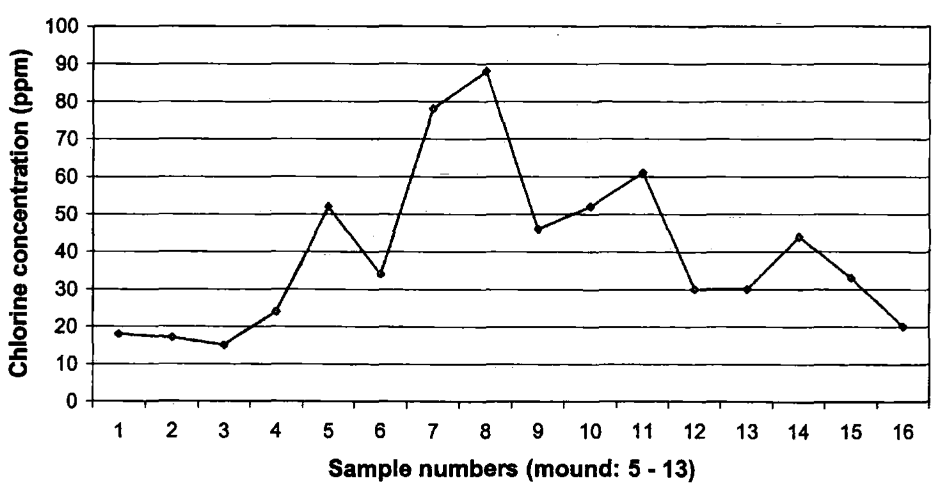


Figure 4-9i: SS#3 Topsoil Chlorine Concentrations



Peaks – The Most Obvious Anomalies

Anomalies are significant deviations from a steady state, which, in these cases, would be represented by a straight horizontal line across each graph, indicating a uniform concentration of the element under consideration across all samples from a given mound. It is obvious that there are some strong anomalies shown in most of these graphs. For all three mounds there are high spikes in the lead concentration at various points, which are particularly high over the mounds themselves. These anomalies are strongest for Sturdy Springs (SS) #1 (Figure 4-7b), less for SS#2 (Figure 4-8b), and least for SS#3 (Figure 4-9b). The number of such peaks also differs from mound to mound, with SS#3 having fewer than the other two mounds.

The lead pattern of peaks in the three mounds is more or less repeated, at lower levels, in the graphs of several other elements. Copper and zinc produce peak patterns for all mounds very similar to each other in location, although the zinc peaks are clearly more exaggerated than those for copper on SS#2 (Figures 4-8c & a), and slightly more for SS#3 (Figures 4-9c & a), but are much less high than those for copper on SS#1 (Figures 4-7c & a). The locations of the copper and zinc peaks are also roughly similar to those for lead.

The concentrations of arsenic, generally low, in a small way follow those of lead over all three mounds. The same is true of titanium, which is present in relatively large amounts in all samples, but increases at the same points as arsenic.

Phosphorus concentrations over SS#3 (Figure 4-9e) correspond little to the patterns of lead, copper and zinc, but some resemblance to the peaks for those metals can be seen for phosphorus over SS#1 and #2 (Figures 4-7e and 4-8e).

The nickel concentrations remain very low across all three mounds, but where there are slight increases, they also tend to be from the same samples which produced large lead peaks. Tin is essentially non-existent in all samples, and where concentrations could be measured, there seems little, if any, effect on the tin concentration comparable to the steep increases seen at some points for lead and, to a lesser extent, for the other above-mentioned elements.

Interpretation of Peaks

The most important conclusion to be drawn from a study of the peaks is that a specific group of metallic elements all generally increase together, to a greater or lesser extent, at approximately the same points. It is likely that virtually all the peaks are due to the presence of the same type of material, in which lead is the major component. Since the Sturdy Springs burnt mounds are located on an army firing range, and quite a few bullets were found in the topsoil when SS#1 was excavated, it was almost certainly bullets, and perhaps their casings, which were responsible for the peaks, overwhelming any effect from other materials which might otherwise produce smaller anomalies.

As a result of these findings, a corroded bullet found in the topsoil of SS#1 was submitted for EDXRF analysis. Initially, the whole bullet was analysed under vacuum, which produced the following readings: copper – 84.73%, zinc – 9.56%, and lead – 5.19%, which total 99.48%, plus trace elements: manganese, iron, molybdenum, antimony, and niobium. Then the inner material from the bullet was analysed, which resulted in quite different readings: lead – 87%, antimony – 12%, and tungsten -0.4%. These results indicate typical rifle bullets, normally made from lead (plus various alloyed metals), and encased with brass (Alloway 1995, 51). The three major components of the bullets are not surprising, as they are the principal metals which have shown strong anomalies in the soil samples, with lead generally producing the largest anomalies, and copper and zinc, the main components of brass, showing especially similar results. Also, arsenic is a chalcophilic metal (as are lead and zinc), which means that it tends to be found together with copper. The metals in this group are often found in nature compounded with sulphur, sometimes two of them in the same compound, as, for example, in tennantite (Cu_3AsS_4). This tendency for similar chemistry may account for the weaker, but similarly located, peaks of arsenic. Nickel, while not classed as chalcophilic, is still considered a metal often associated with copper, which may account for its slight similar peaks (*ibid*, 40 and 43).

There are some additional questions to answer. Why do the peaks for a single element on a given mound vary in height? The most important factors here are probably the distance of the affecting bullet(s) from the sample location, and the number of those bullets in each case. Also, the relative amounts of the different metals present in the peak samples are not always the same from one sample to another. This could be caused by different types of bullets made with different compositions, but at least two other factors may be involved: the relative rates of decomposition of the various metals forming the bullets, and the length of time the bullets have been lying on the ground decaying. The army acquired the land on which these burnt mounds lie in 1940 (P. Abramson, Army archaeologist, pers. comm.) and presumably it has been used as a firing range since then, so quite likely there are remains of bullets lying on or near the mounds in all possible states of decay dating from that time until now.

Why do the #1 and #2 mounds have more peaks than the #3 mound, with the #1 mound having the highest, #2 next, and #3 last? The #1 mound is in open country with no trees on top or surrounding, while the #2 mound is partially, and the #3 mound more completely, in a wooded area. Therefore the #1 mound is the most likely to have been often in the line of fire and received bullets, #2 less so, and #3 least of all. It is possible that, in earlier years (but still while the location has been in use as a firing range), all three mounds were essentially unwooded. In that case, the bullets on SS#3 would be expected to be mainly older and more decomposed than those on SS#2 and especially SS#1. This does seem to be the case, judging by the lower concentrations of, for example, both copper and lead, in sample 8 from SS#3 (Figure 4-9a & b) as compared with the peak concentrations from SS#1 and #2 (Figures 4-7a & b and 4-8a & b). Also, the ratio of copper-to-lead is less for SS#3, sample 8 than it is for the peak samples from SS#1 and #2. This shows that more of the copper than lead has leached away already from the SS#3 sample than from the SS#1 and #2 samples (although both rates would vary with the pH of the soil). Simon Timberlake, reporting on XRF analysis at Alderley Edge, corroborates that the leaching rate of copper is faster than that for lead: "Lead, being fairly insoluble to the leaching process, is left as a residue in much larger amounts" and "relatively soluble copper is present at much lower levels" [than lead]. (Timberlake and Prag 2005, 234) Such differential rates of leaching may also explain why zinc is stronger in samples from SS#2 and #3 than from SS#1.

The phosphorus concentrations roughly follow the lead pattern for SS#1 and #2, but not for SS#3, where the concentrations generally increase as they proceed over the mound and are especially high over the stream, which at this point is more of a stagnant swamp due to the original stream having been diverted. The #3 mound, but not the other two, is full of rabbit holes, so it seems likely that any phosphorus in the samples from #3 relating to bullets, which are in any case apparently fewer than on the other two mounds, has been largely obscured by that from rabbit droppings which have tended to be washed down toward and into the stagnant stream. Phosphorus concentrations, especially in mounds #1 and #2, bear some similarity to those for sulphur and chlorine, probably because all three tend to be present in soil as negative ions (phosphates, sulphates, and chlorides, respectively), which react similarly, combining with the positive ions of most metals to form compounds, but also with hydrogen to form phosphoric, sulphuric, and hydrochloric acid, increasing the acidity of the soil. (Tan 1998, 377-8)

Why are there more high peaks over the mounds than on the adjacent land? This is the hardest question to answer. Perhaps their very "moundness" for some reason made them even more susceptible to bullets than the surrounding territory. They may have provided targets to shoot at, or perhaps soldiers used them as cover for shooting into the distance, discarding unusable or excess bullets or inadvertently dropping bullets on them.

Dips in Concentrations across the Mounds

Leaving aside the peaks apparently caused by bullets, there is some decrease in the concentrations of metallic elements across the remainder of the mound area, as compared with the ground beyond the mounds. This effect is most clearly shown in the graphs for SS#3 (Figures 4-9a – h). The much stronger and more numerous peak anomalies in SS#1 and #2 (Figures 4-7a – h and 4-8a – i) tend to obscure the dips which would probably also be apparent in them otherwise. Nevertheless, the dips for SS#1 and #2 would likely be less than for SS#3 in any case. The decreased concentrations over the mounds must be due to the same leaching process already discussed in relation to bullet contamination, only here we are dealing with selective leaching of soil components in samples relatively unaffected by bullets. In the case of SS#3, the significant dip across the mound for most elements shows that the mound must be more permeable by water than is the surrounding ground, and also probably more permeable than the other two mounds. The composition of SS#3 appears to be different from that of the other two, richer in charcoal and with fewer stones, making it less compacted, the probable reason why it seems more susceptible to leaching than the neighbouring mounds – and also why the rabbits favour it! As suggested in Chapter 3, when there is one mound of this type in a group of burnt mounds, it may be the earliest of the group, and has been scavenged for reusable stones by the users of the nearby later sites. The depths of the dips for different elements in SS#3 provide a rough idea of the relative susceptibilities of the various elements to the leaching process. From the graphs it appears that zinc leaches fastest, then copper, probably lead (questionable, since mostly obscured by peaks), arsenic, nickel, and last, titanium.

Other Anomalies

Calcium, magnesium, and aluminium concentrations generally show significant dips in concentrations over the mounds, but, in the case of calcium, there is a huge increase in concentrations in the samples taken from below the stagnant water of what should be the stream beside SS#3. It seems most likely this is due to the build-up, then deposition of calcium compounds dissolved from limestone, which is abundant in the area, and very likely present in the stream water. In the flowing water beside the other mounds these compounds would not precipitate out to nearly the same extent.

Overall, nothing in the topsoil survey suggests that copper was utilized in the ancient operations at the Sturdy Springs site.

Results from the SS#1 Excavation

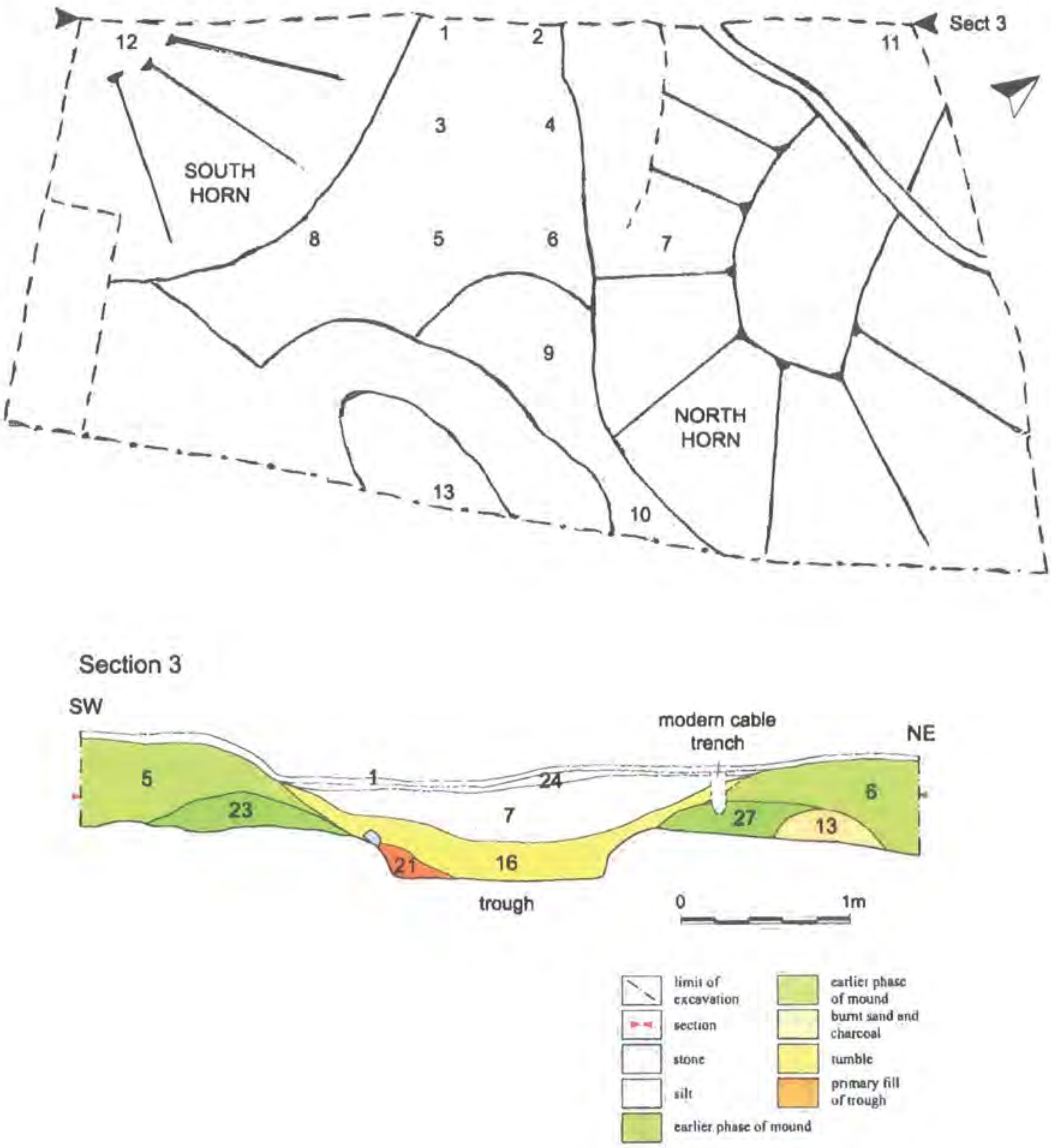
The locations of contexts within mound SS#1 from which 17 samples were taken during excavation (listed in Table 4-1) can be found from the plan of the top of the uncovered original mound and/or the section drawing (both in Figure 4-10).

Table 4-1: SS#1X Excavation Sample Contexts

Sample #	Context #	Description of Material
1	7	Deposit in centre of mound
2	7	" " " " "
3	7	" " " " "
4	7	" " " " "
5	7	" " " " "
6	7	" " " " "
7	6	North horn deposit
8	7	Deposit in centre of mound
9	10	Gully fill
10	10	" "
11	6	North horn deposit
12	5	South horn deposit
13	8	Mound in entrance
14	23	Top of primary deposit in south horn
15	6	Bottom layer just above top of primary deposit in north horn
16	13	Deposit within north horn
17	21	Primary fill of trough

Figure 4-10: Plan and Section Views of Sturdy Springs #1 Showing Sample Contexts

Numbers on plan view: sample numbers
Numbers on section view: context numbers



Source: Archaeological Services Durham University
(Plan view based on drawing by Janet Beveridge, ASDU)

In general, the numbering of the contexts begins with 1 at the top of the mound, and the numbers increase as lower levels are reached. Therefore, on the graphs showing concentrations of various elements in these internal samples (Figures 4-11a - i), as the sample numbers increase, the samples originate from progressively lower levels. Sample 15 could not be made into a pellet and so its concentrations are missing from the graphs.

Sample 11 Anomalies

The first things which will be noticed in the SS#1X set of graphs are the huge concentrations of both copper and lead in sample 11, out of all proportion to those in all the other samples. Unfortunately the zinc concentration could not be measured from this sample, but, noting that both arsenic and titanium are also unusually high in sample 11, and even nickel is slightly raised, the pattern seen in the over-the-mound samples, which probably represents the influence of modern bullets located on the top surface of the mound, can be discerned. What is shown here appears to be the effect of leaching through a considerable depth of topsoil, silt, and some ancient mound material. That the copper and lead concentrations at this level are almost equal is a clear indication of the faster rate of leaching of copper as compared with lead, since near the surface, in the over-the-top samples, the copper concentration is always less than half that of lead (as shown in Table 4-2).

Table 4-2: Copper/Lead Concentrations in Bullet-Affected Samples

Sample #	Copper/Lead Concentration Ratio (concentrations in ppm)	Decimal Ratio
Over-the-top samples:		
SS#1 – 10	726 / 7900	0.092
" 1 – 11	242 / 2800	0.086
" 1 – 12	491 / 1100	0.446
" 1 – 15	243 / 2600	0.093
SS#2 – 9	90 / 440	0.205
" 2 – 12	63 / 1200	0.053
" 2 – 13	69 / 5600	0.012
" 2 – 15	48 / 283	0.170
" 2 – 17	43 / 256	0.168
SS#3 – 8	50 / 504	0.099
Excavation sample:		
SS#1X – 11	5200 / 5300	0.981

Figure 4-11a: SS#1X Copper Concentrations in Excavation Samples

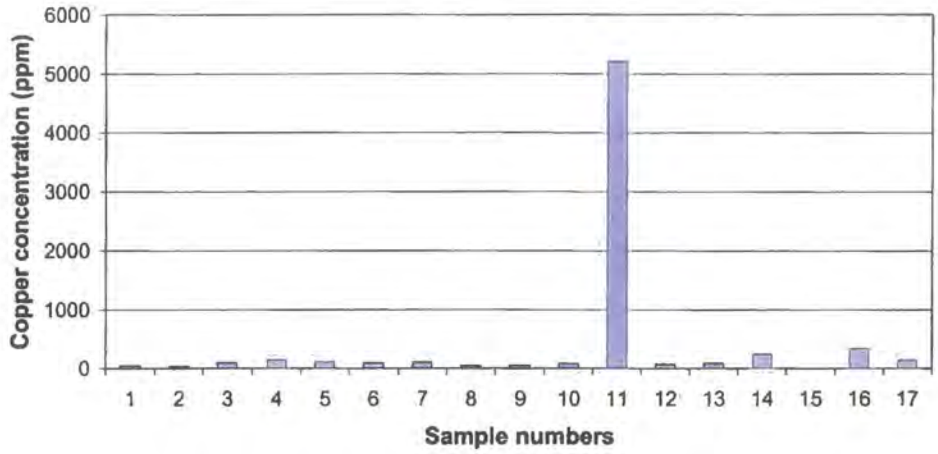


Figure 4-11b: SS#1X Lead Concentrations in Excavation Samples

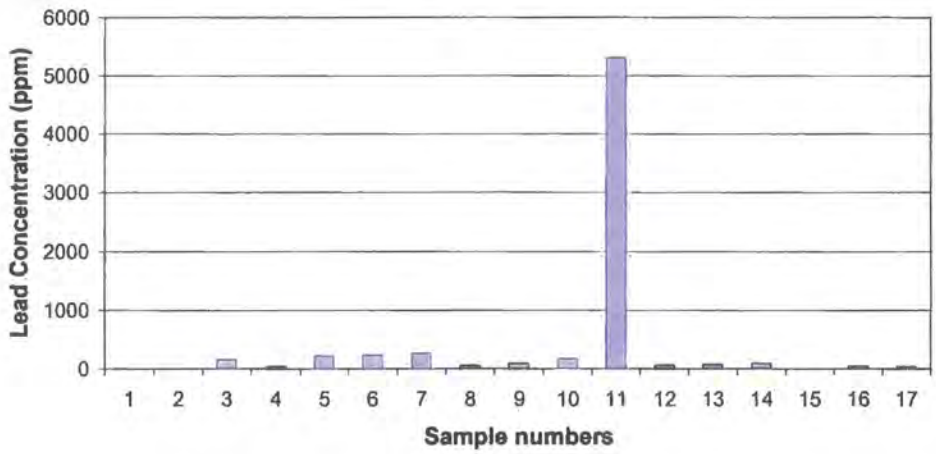


Figure 4-11c: SS#1X Zinc Concentrations in Excavation Samples

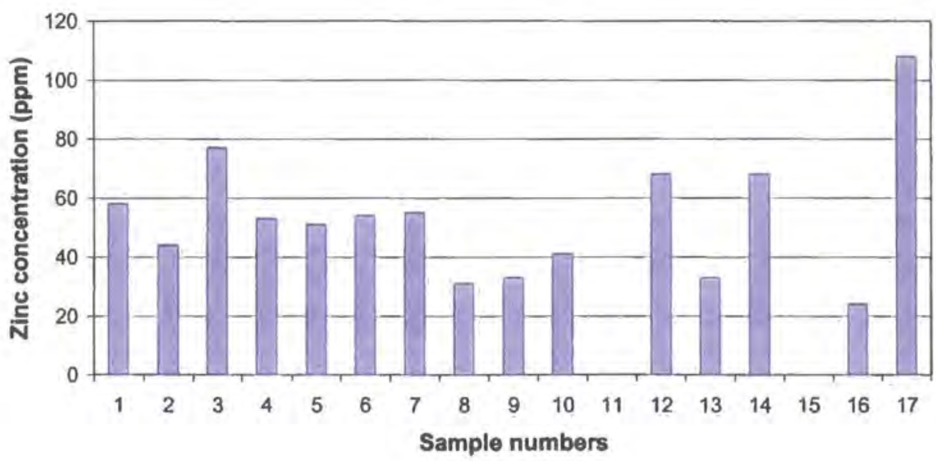


Figure 4-11d: SS#1X Nickel Concentrations in Excavation Samples

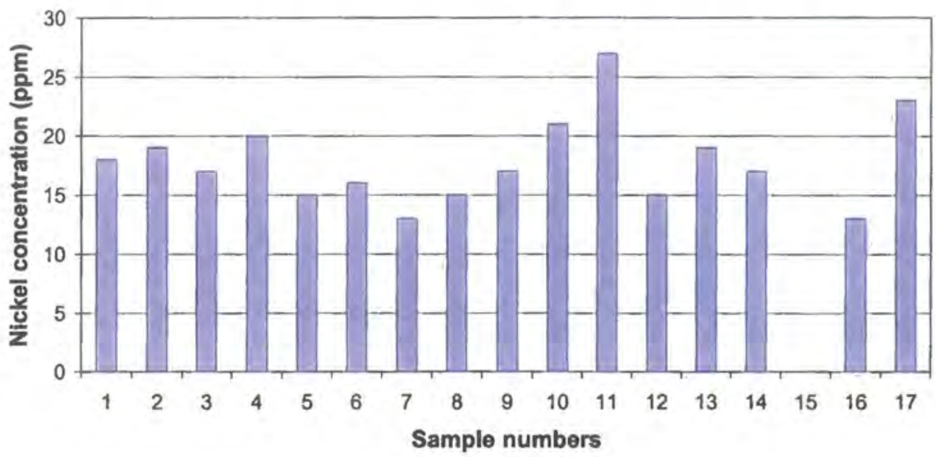


Figure 4-11e: SS#1X Phosphorus Concentrations in Excavation Samples

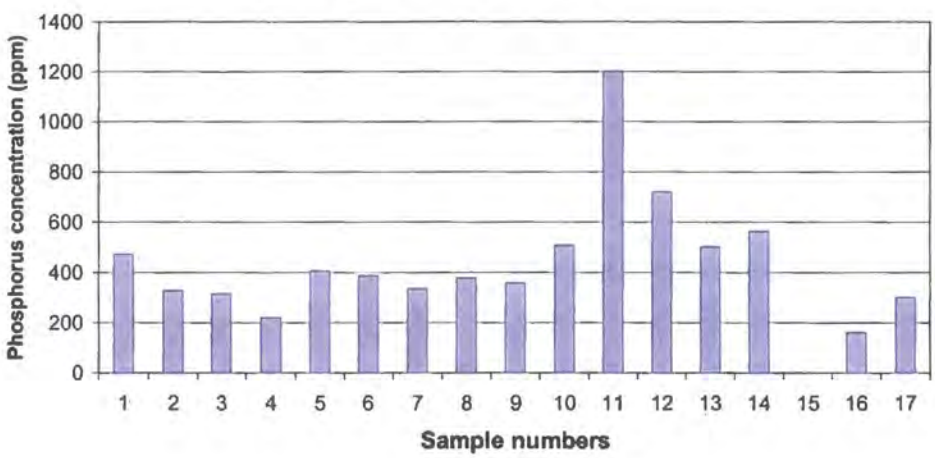


Figure 4-11f: SS#1X Arsenic Concentrations in Excavation Samples

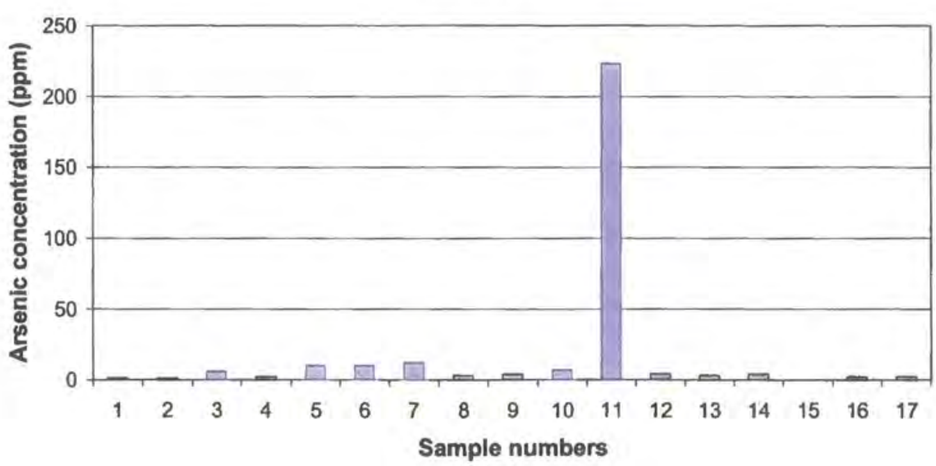


Figure 4-11g: SS#1X Titanium Concentrations in Excavation Samples

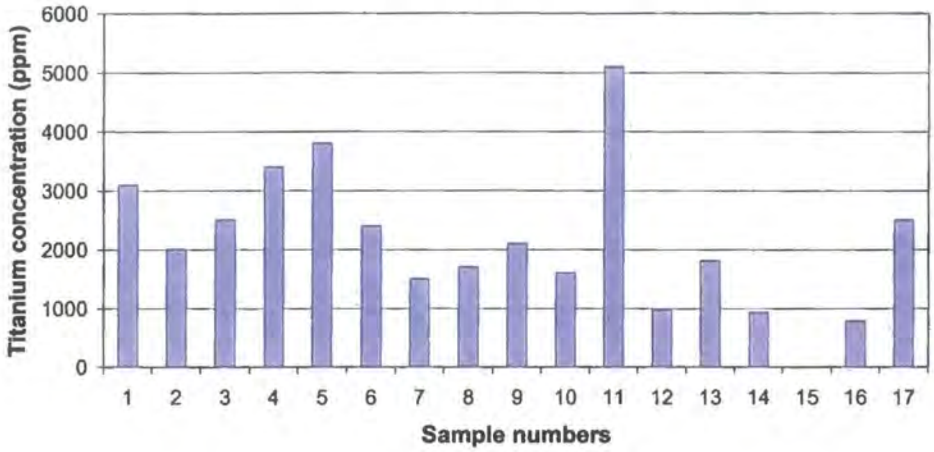


Figure 4-11h: SS#1X Sulphur Concentrations in Excavation Samples

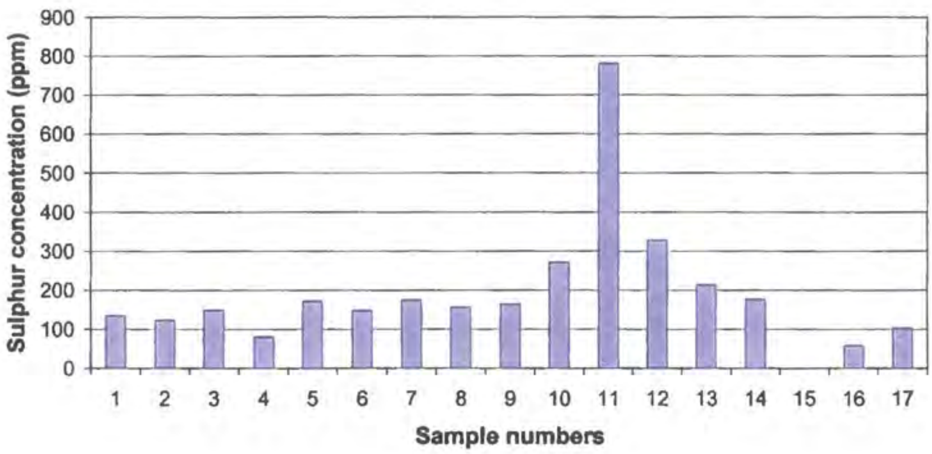
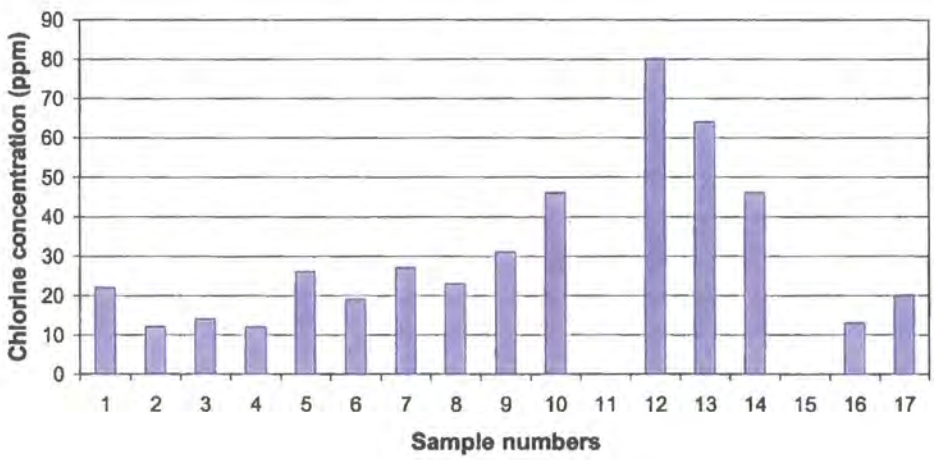


Figure 4-11i: SS#1X Chlorine Concentrations in Excavation Samples



It might also be noted that, for the over-the-top samples, higher copper/lead ratios are likely to indicate newer bullets, and lower ratios, older bullets, since the copper in the bullets is mainly on the outside, and is disappearing downward faster than the lead, leaving less and less remaining at the top for further leaching, as compared with the amount of lead.

Other Samples

Except for sample 11, the other samples do not show any consistent pattern among the various metallic elements. Looking at the graphs for copper and lead in particular, the patterns seem to be roughly reversed, with copper concentrations highest in samples 14 and 16, from almost the lowest of the contexts, while lead concentrations are highest in samples 5, 6, and 7, nearer to the top of the mound. Most likely this is also an effect of leaching, where copper, naturally in the soil and/or emanating from bullets more distant than was the case for sample 11, is being leached at a more rapid rate than that for lead, so more is found at lower levels, while more lead remains at higher levels. However, this is also somewhat the pattern which might be expected if copper ore were being processed. Lead, being a chalcophilic metal often found in nature together with copper, would be part of the "gangue" which would have been separated from the copper compounds and thrown on the rubbish heap, while the copper was treated at ground level. But this is a remote possibility as an explanation for the pattern observed, because of the extent to which leaching would have much earlier affected the concentrations and locations of the elements initially present.

Conclusions

Given that layers of topsoil and silt were found under the turf and above the original mound material when SS#1 was excavated, the samples taken over the tops of the mounds were unlikely to contain much, if any, actual burnt mound material. Therefore, evidence of ancient copper processing could hardly be expected from those samples. XRF analysis was successful in identifying a probable copper processing site at Great Orme, but in that case a portable XRF analyser was used, which was placed against the ground surface to take readings (Jenkins *et al.* 2001, 165), and therefore could perhaps have recorded concentrations from lower depths than those of the samples from the present research. Also, in the Great Orme case, there may have been less of an overlay of modern soil. Nevertheless, the topsoil sample analyses have been useful in elucidating the leaching process, which has been shown to be important for judging where to look for copper. The samples from within SS#1 have also failed to produce any clear evidence of copper processing at the site. However, this does not prove definitively that no such processing ever happened there. To understand why, the factors which make the detection of such processing difficult should be considered (assuming, for the moment, that burnt mounds were copper production places):

- From the size of burnt mound sites and their simplicity, it is certain that, at best, only small amounts of copper could have been produced at one time.
- Most likely, only relatively small amounts of ore would have been brought to the site at one time, perhaps only what one person could carry.
- The ore would have been broken up and crushed, either at the site or some previous place. The crushed particles would have had a large surface area compared with volume; therefore, any which contained copper, but were accidentally thrown away with the gangue would have been particularly susceptible to leaching.
- If the crushed copper compounds were turned into copper metal, this product would have been removed from the site to be put to use elsewhere.
- As copper must have been precious, every bit of waste material containing it which could be found must have been collected and reprocessed.
- All of the above together imply that very little copper would be expected to have remained at the site when it was abandoned.

What little copper did remain would have rapidly leached away. The experimentation described in this chapter shows that copper leaches more quickly than most other metals which comprise bullets. The bullets present on the Sturdy Springs mounds cannot have been there for longer than 67 years, 2/3rds of one century, yet the copper in them has already decomposed and leached away to a considerable extent. Imagining a similar rate of leaching for any copper which had been left behind from ancient processing roughly 30 to 40 centuries ago (based on the radiocarbon dates obtained for SS#1 and 3, respectively), it is highly unlikely that there would be any detectible amounts of that copper now remaining on or above the old ground surface at the sites. The only possibilities for preservation until now would probably be: 1) pieces which were originally quite large, or 2) bits that had some sort of protective covering not permeable by water.

The XRF method might be more effective in finding copper which was present so long ago if a portable analyser were used (as was done in both the Great Orme and Alderley Edge cases), and were applied directly to a mound in process of excavation, and to its trough, hearth, and ground surface. This procedure might detect leached copper at some depth below surfaces. All in all, its evidence would probably best be combined with indications of copper processing using other approaches.

Chapter 5

BURNT MOUNDS AND COPPER SOURCES

"wherever these ancient hearths are found the vicinity is a favourable field for mine adventurers" – Walter Davies, 1810

Almost 200 years ago Walter Davies (1810, 41) thought he saw a relationship between the locations of burnt mounds and the locations of mineral deposits. Was he right? The research described in this chapter attempts to find out. If burnt mounds were indeed "ancient British smelting-hearths", as Davies assumed, it is likely that large numbers of them would be found rather close to their principal raw material, which in the Bronze Age would have been copper ore. (For the making of bronze, tin would have been needed as well, but, as bronze is about 90% copper and only 10% tin, siting burnt mounds near copper sources would have been the more likely choice. Besides, tin is only available in usable amounts in one area of the British Isles, southwest England, while burnt mounds are spread widely throughout.)

Whether or not copper supply influenced the choice of burnt mound site locations, there are other factors which clearly did. For example, a dependable water supply such as a stream or boggy ground, an abundance of fuel (trees or peat), an appropriate form of stone, and clay soil all appear (as shown in Chapter 3) to have been important considerations in selecting burnt mound sites. Assuming that burnt mounds were copper-processing sites, the choice of a site must often have meant a compromise between proximity to a copper source and the right environment for the processing operation, so varying distances between copper sources and burnt mound concentrations would be expected. There would also likely be some isolated outlying mounds where other factors overrode copper source location entirely, or where a different use might have been found for the same type of site. Therefore, in this part of the research, attention is focused principally on where the large, dense groupings of burnt mounds are located, and how those groupings are positioned with respect to copper source locations.

Methodology

The basic plan of the research was to collect as much specific information as possible about the locations of both burnt mounds and copper sources throughout the British Isles, prepare maps showing both types of locations, then compare the maps to ascertain any correlations between the concentrations of burnt mounds and the locations of copper sources.

Collection of Burnt Mound Location Data

Information about locations of burnt mounds has been collected from a variety of sources. For the United Kingdom, data were collected entirely in the form of NGR coordinates for burnt mound sites. County or archaeological unit SMR/HERs were the basic sources for England, Wales, and Northern Ireland. In a few areas of England the SMR information could not be accessed, and these are indicated on the map. For Scotland a gazetteer was available. For Ireland a combination of data from county archaeological inventories and figures for each county given in a 1991 article were used. All of these sources have been supplemented by others, wherever additional information was found. For the Isle of Man a map was available with all known burnt mound locations already shown on it. All the data sources for all of the burnt mound maps are listed at the end of the chapter as Table 5-1. As the data were collected, questionable sites, for instance, many of those described as "possible burnt mounds", were eliminated from the listings wherever sufficient information was provided to make a judgment. The quality and completeness of the data is bound to vary somewhat from area to area, depending on how fully and carefully each has been searched for burnt mounds, and to what extent urbanization or ploughing has destroyed large proportions of mounds which may originally have been present.

Collection of Copper Source Data

Locations of mineral veins and copper-producing mines and deposits were mainly found in maps, tables, and sometimes text in reference books which had been prepared primarily with modern mining prospectors as expected readers, and which therefore emphasized large, commercially viable deposits, probably ignoring some lesser sources which could also have been exploited in the Bronze Age. The mines selected for this chapter's maps often produced commercially several different metals, but in all cases copper was either a major or minor product. In most cases the locations of copper sources were not given in NGR coordinates, so it was necessary to estimate their positions. As some references consulted cover more than one part of the British Isles, all are included in a single list at the end of the chapter as Table 5-2.

In general, it should be clear from the titles to which parts of the British Isles they refer.

Mapping of Burnt Mound Locations

The listings of burnt mound NGR coordinates for England, Scotland, and Wales were entered into a computerized database, then, using GIS, placed on appropriate maps. Although a single dot was used for each burnt mound location, many mounds were so close to others that it is impossible to distinguish the dots for two or more different mounds. On the England map, where most data was from SMR/HERs, the few areas for which it could not be obtained in this way are shown in grey; for some of these, other sources supplied some information. The number of burnt mound locations placed on the maps for England, Scotland and Wales totals 3,755. For Ireland the total burnt mounds in each county were indicated by a number placed on that county's space on a map of Ireland. This simpler method was used due to the extremely large number of burnt mounds in Ireland and the form in which the information was available.

Mapping of Copper Source Locations

Because in most cases copper source locations were not given in NGR coordinates, they had to be placed on maps according to sight comparison with reference maps, the name of the nearest town, or other clues gleaned from the references. Where they could not be fairly accurately located, they were not included on the maps which were prepared. For England, Scotland, Wales, and Ireland copper source locations were placed on maps separate from those for the corresponding burnt mound areas but identical in scale for ease of comparison. In some cases where two or more mines were close together, one symbol has been used on the maps to represent more than one mine, the purpose of the symbols being to identify areas where copper was likely to have been available for Bronze Age people to use, rather than to count numbers of mines. The Isle of Man copper source information was placed directly on the map showing burnt mounds, as in this case the scale was large enough to avoid confusion.

For Wales and Northern Ireland, additional maps, based on soil concentrations of copper, were available and so were added to provide extra aids for comparison, but they must be used with caution. The locations of modern mines indicate where there have been large enough mineral deposits to be commercially viable for exploitation in recent centuries, but for the undoubtedly far smaller operations of the Bronze Age, much smaller sources could have been usable. Except in the relatively few cases where Bronze Age mines have been identified, it is difficult to know where small sources used at that time may have been. The highest concentrations shown on the soil concentration maps can suggest areas where there may have been small deposits of copper available, but not too much weight can be given to this evidence, because other causes, such as human habitation and industrial pollution, may contribute to raised modern copper concentrations in soil, without any relationship to sources that would have been available in the Bronze Age.

Comparison of the Two Sets of Maps

First, in each set of maps for a given region, the locations of dense burnt mound concentrations were identified, then these were compared with the locations of copper sources to decide which burnt mound groupings were close enough to be considered related and which were not.

Interpretation

An attempt was then made to explain the outcome of the comparison of each set, and finally to combine the results from all sets into a general outcome for the British Isles as a whole.

Map Results, Comparisons, and Interpretations

The Distribution of Burnt Mounds in Scotland (Figures 5-1a & b)

The Orkney and Shetland Isles have been placed on a separate map from the remainder of Scotland so that both parts may be shown at larger scales, with the positions of the burnt mounds on them more readily identifiable. The densest concentrations of burnt mounds in Scotland are found throughout the Northern Isles and in the southernmost part of the mainland. In the Northern Isles the mounds are spread thickly over most of the islands (except for the northernmost part of Shetland), including even Fair Isle.

In mainland Scotland along the southern coast are two dense groupings of mounds, one in the Kirkcudbright area and the other toward the western end of

Figure 5-1a: The Distribution of Burnt Mounds in Mainland Scotland and the Western Isles

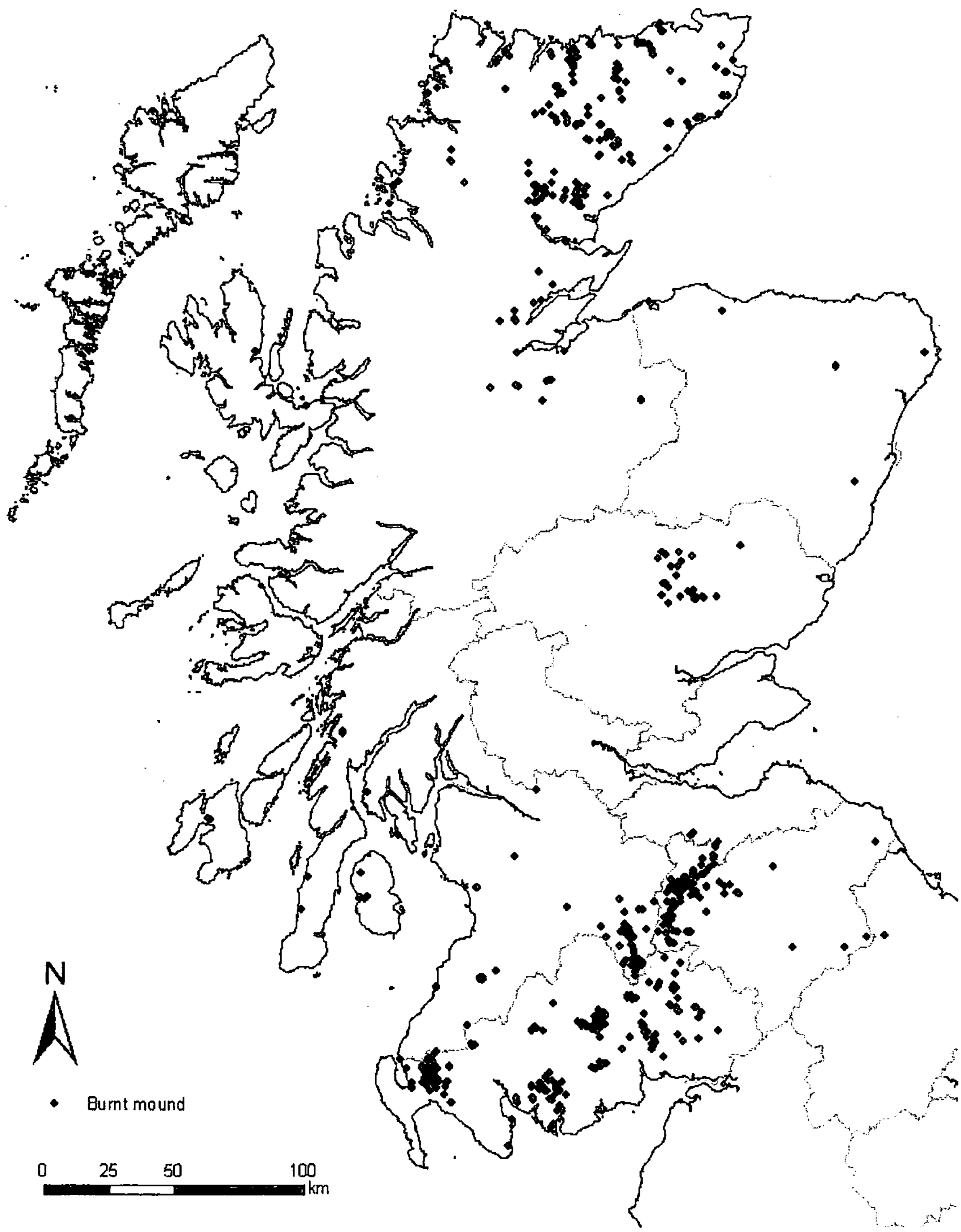


Figure 5-1b: The Distribution of Burnt Mounds in the Northern Isles of Scotland

Dumfries and Galloway. Northeast of Kirkcudbright, extending to an area just south of Edinburgh, is a very large conglomeration of burnt mounds. The straight lines of mounds evident in several places within this grouping are almost certainly the result of watching briefs along either road or pipeline construction sites, which suggests that if the area adjacent on either side of such lines were subjected to the same degree of scrutiny, even more burnt mounds would likely be found there.

A somewhat less dense but widespread concentration appears in the north-eastern Highland area. Most of these mounds were recorded during a survey specifically undertaken to identify burnt mounds in that area (Blood 1989). There is also a slighter concentration located between the southern and northern ones.

Only a couple of burnt mounds have been found in the Western Isles, and a few scattered ones on the isles close to the mainland, but this paucity, and indeed that of the entire midsection of the Scottish mainland, could be at least partially due to these areas having been less thoroughly searched for burnt mounds than the far south and north.

Copper Sources in Scotland (Figures 5-1c & d)

The same separation of Scotland into the Northern Isles and the remainder has been used for the copper source maps, for ease of comparison with the burnt mound maps. There are no known Bronze Age copper mines in Scotland (Timberlake 2003, 37), but there have been many modern mines and mining attempts.

Several bands of mineralization cross Scottish territory and are differently described in different books. The divisions used here are from Wilson 1921. The southernmost of these, extending approximately to the latitude of Edinburgh, contains two areas which have been major suppliers of metals in modern times. One is represented by the group of mines shown on the map along the southern coast ranging roughly from Kirkcudbright to Wigtown, with several outlying mines at some distance. "In this part of Scotland [Kirkcudbright], thin veins carrying copper ores are fairly abundant along the coast, and easily recognized by the bright green colour of their secondary minerals" (Wilson 1921, 120). The other mine-rich place is the Leadhills area, shown by a group of four mining spots northeast of the coastal group. As the name indicates, most of the Leadhills mines primarily produced lead, but copper and lead are found in particularly close association in southern Scotland, and

Figure 5-1c: Copper Sources in Mainland Scotland and the Western Isles

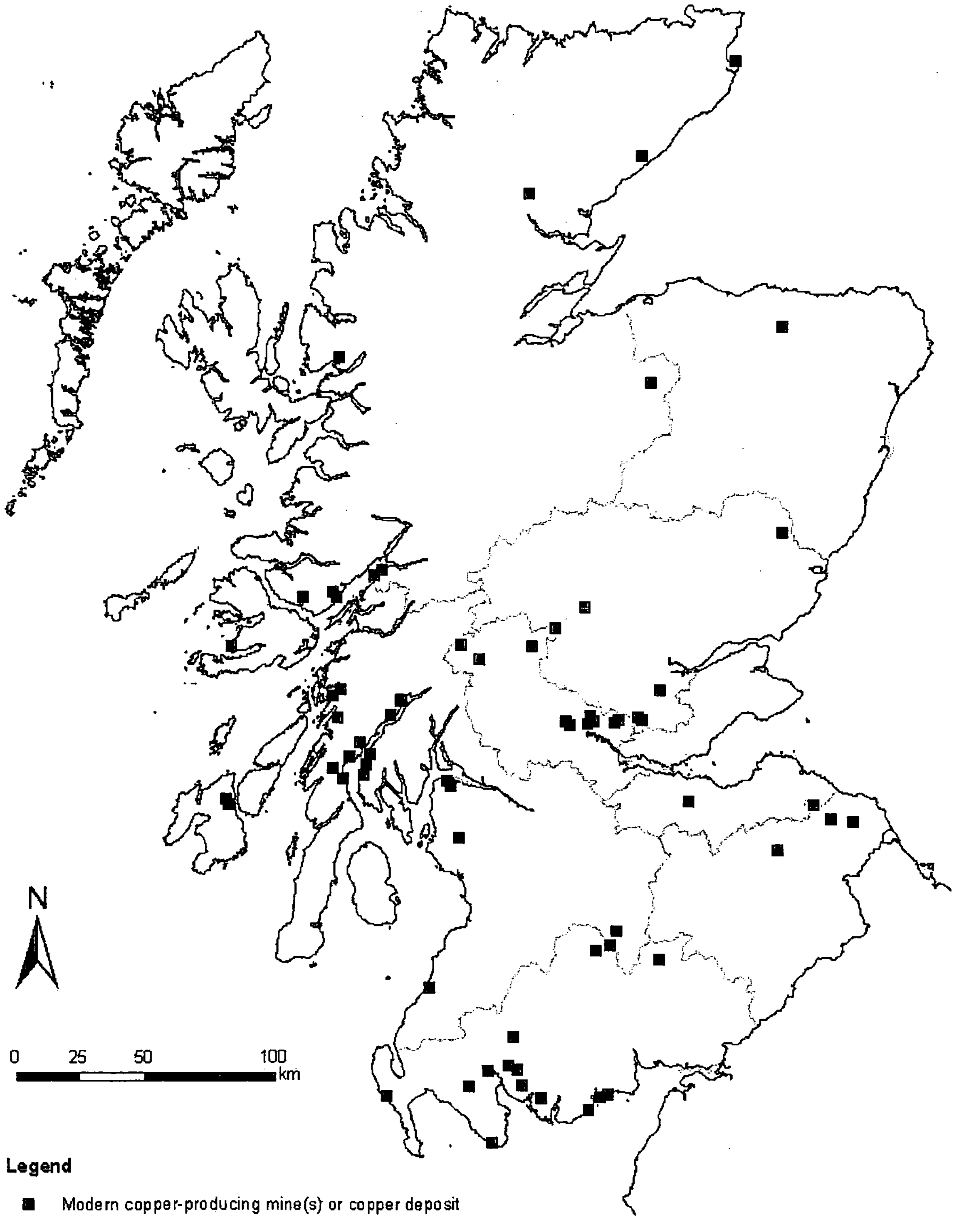
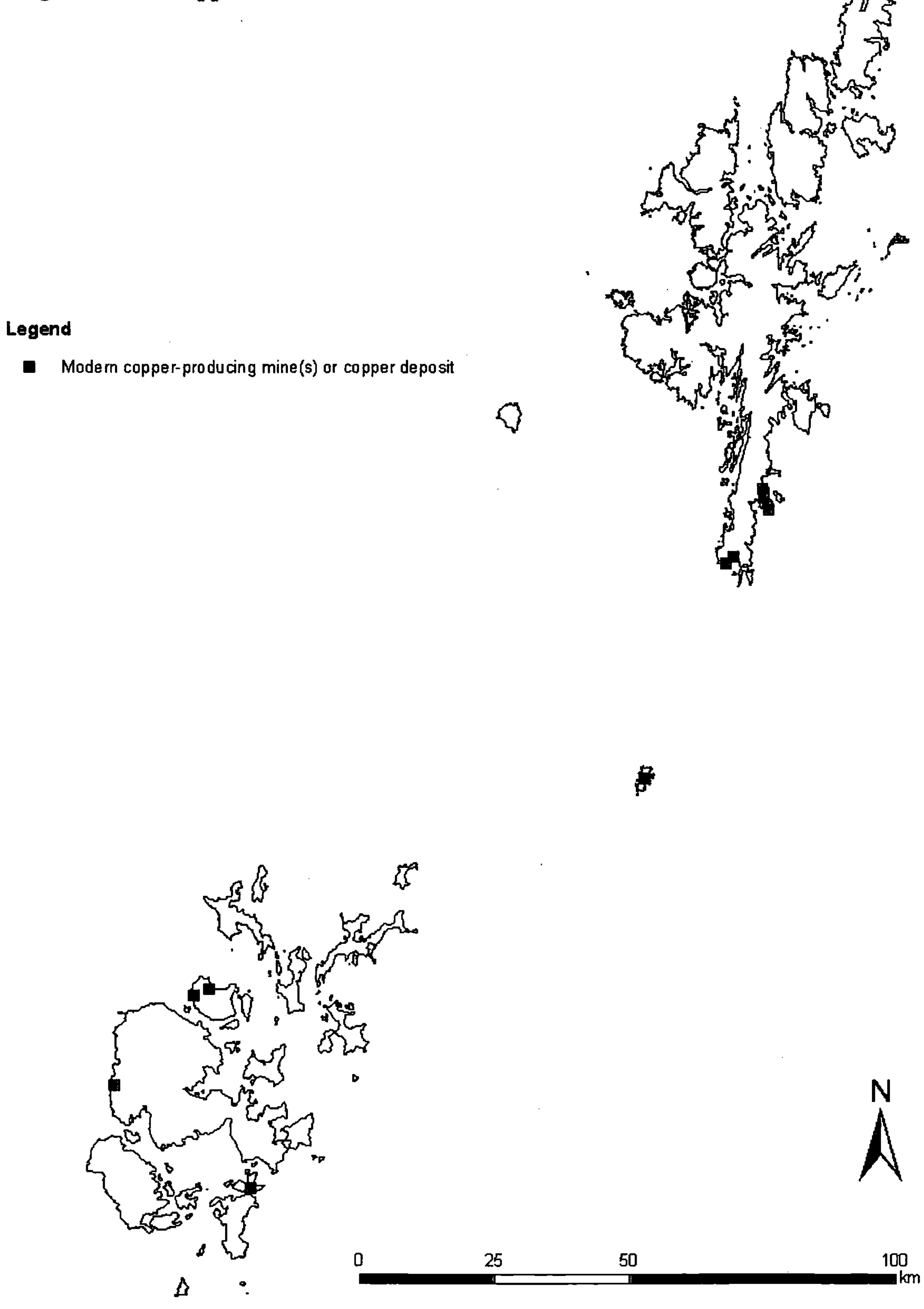


Figure 5-1d: Copper Sources in the Northern Isles of Scotland



copper was a by-product from many basically lead mines, including these. There are also several primarily copper mines in the area between Edinburgh and the east coast, and a few along the west coast near Glasgow. A number of additional lead mines are found between Leadhills and Edinburgh, but they are not shown on the map because no specific information has been found indicating that they produced any copper, although given the nature of the mineralization in this band, it is quite possible that there was some copper present.

The next band of mineralization extends north to a rough line from Aberdeen on the east to Glencoe on the west. There are two particularly important copper concentrations here. The most extensive is along both sides of Loch Fyne from Inverary south and then ranging north toward the coast at Loch Melfort. Many copper and lead mines are found in this area. There have also been copper mines on Islay and one on Mull, and several on the mainland from Mull to and around Loch Linnhe. Another important area for copper is north and east of Stirling where several mines have existed. Some copper is also found among the lead mines at Tyndrum and along the south shore of Loch Tay, as well as near Fettercairn.

The third mineralization band, comprising the remainder of Aberdeenshire and Highland except for Caithness, as well as the Western Isles, has only widely scattered, mostly individual mines.

The fourth band includes the Northern Isles and Caithness. There have been at least four copper mines in Orkney, on three different islands, and in the southern half of mainland Shetland, the Sand Lodge mine produced significant amounts of copper into the 20th century with a few other mining attempts grouped around it. Fair Isle, too, is known to have copper deposits, although no modern mining has occurred there. There is some copper and has been an attempt to mine it near Wick.

Map Comparison and Interpretation

In the far north and far south the maps of burnt mounds and copper sources in Scotland match rather well. In the Northern Isles where burnt mounds are most dense and almost ubiquitous, there are a number of known copper sources spread over Orkney, Shetland, and Fair Isle. These sources are not on every island, but it seems likely that it was easier to travel over water than over land in the Bronze Age. There is little evidence for the use of the wheel or horses for transport during the Bronze Age in the British Isles, but several examples of Bronze Age boats have been found

(Harding 2000, 165-70, 177-86). Ore could have been readily transported from one island to others, the islands within each group being quite close to each other. That many burnt mounds were located near the coasts also supports this possibility.

In mainland Scotland, both burnt mounds and copper sources are abundant in the southernmost band. In the Kirkcudbright coastal area, mines are located along the coast and burnt mounds found slightly inland. The line of mines continues to the Wigtown area, somewhat close to the other very dense concentration of burnt mounds along this coast, which may also have been related to a couple of other coastal copper mines not far away. To the northeast of the coastal concentrations, the extensive grouping of burnt mounds reaching almost to Edinburgh covers much the same area as the Leadhills mining district and additional lead mines further to the northeast. The copper mines closer to the east coast, and those near Glasgow, however, do not have any known concentrations of burnt mounds nearby.

There appears to be little relationship between the many mines of the second band and burnt mound concentrations, but there is a small group of burnt mounds on Islay close to the mining area there, and another near a copper mine at Kilmartin. The moderate concentration of burnt mounds to the northeast is between three copper mines, but the distances between burnt mounds and copper are probably too great for any relationship.

In the third band, some small groupings of burnt mounds are rather close to individual mines, especially in the Caithness-Sutherland area where the largest number of burnt mounds have been found.

If copper and burnt mounds are related, why might it be that copper sources appear most numerous in southern Scotland, while burnt mounds are most dense in the Northern Isles? These proportions may be skewed by other factors. For example, an apparently vibrant society existed in the Northern Isles during the later prehistoric period, as testified by the many fine monuments remaining from that time. Such people would likely have been especially eager to make use of the latest knowledge and technology. Being an island people they were undoubtedly adept at sea transport, and could have established trade links with a variety of other places, almost certainly including Ireland, with many similarities in artefacts and construction types in both places. In other words, they may have exploited the copper resources that they had more intensively than did those who lived in southern Scotland.

The Distribution of Burnt Mounds in England (Figure 5-2a)

In England there are four areas which show dense concentrations of burnt mounds: 1) East Anglia, especially Norfolk and Suffolk; 2) northern England, encompassing the Dales area of Yorkshire and County Durham, and with a growing number of recently-discovered mounds in Cumbria and Northumberland; 3) Birmingham and its surroundings, including Shropshire, Telford and Wrekin, Staffordshire, and Warwickshire; and 4) the Hampshire area, especially the New Forest. With the exception of East Anglia, however, the densities are much less than those of the most dense areas of Scotland.

By far the largest of these concentrations is the East Anglian one. However, county archaeologists (C. Pendleton and Jan Allen, pers. comms.) for Suffolk and Norfolk, respectively, both warn that it is questionable whether some of the sites listed as burnt mounds in their areas should actually be classed in that category. Burnt flint seems to have been produced in this area in all periods from Mesolithic to Post-mediaeval and many sites are multi-period, creating a confused dating situation. Also, many sites are almost totally ploughed out, and are simply burnt flint spreads. An attempt was made to sort out the more unlikely cases, although the numbers could still be inflated to an unknown extent. Nevertheless, around the edges of the Wissey Embayment there are "hundreds, if not thousands, of potboiler sites, dating from the Neolithic through the Bronze Age" (Hall, D. and Coles, J. 1994, 60). In this limited area, at the very least, there appears to be a dense concentration of authentic burnt mounds.

Copper Sources in England (Figure 5-2b)

In the roughly half of England southeast of the dotted line shown on this map, there are no mineral veins at all, the land consisting mostly of chalk, limestone and clay (Dunham *et al.* 1978, 264). Within that area there can hardly be any copper sources, even of a size which could have been adequate for Bronze Age use, and no mines appear on the map. On the other hand, southwest England (Cornwall, and extending into Devon) is "the most important metal field in the United Kingdom" (*ibid*, 264). Here both copper and tin have been found in abundance. Other areas of mineralization in England include the Northern and Southern Pennines, the Lake District, part of West Shropshire bordering Wales, and the Mendips. The first four of

Figure 5-2a: The Distribution of Burnt Mounds in England

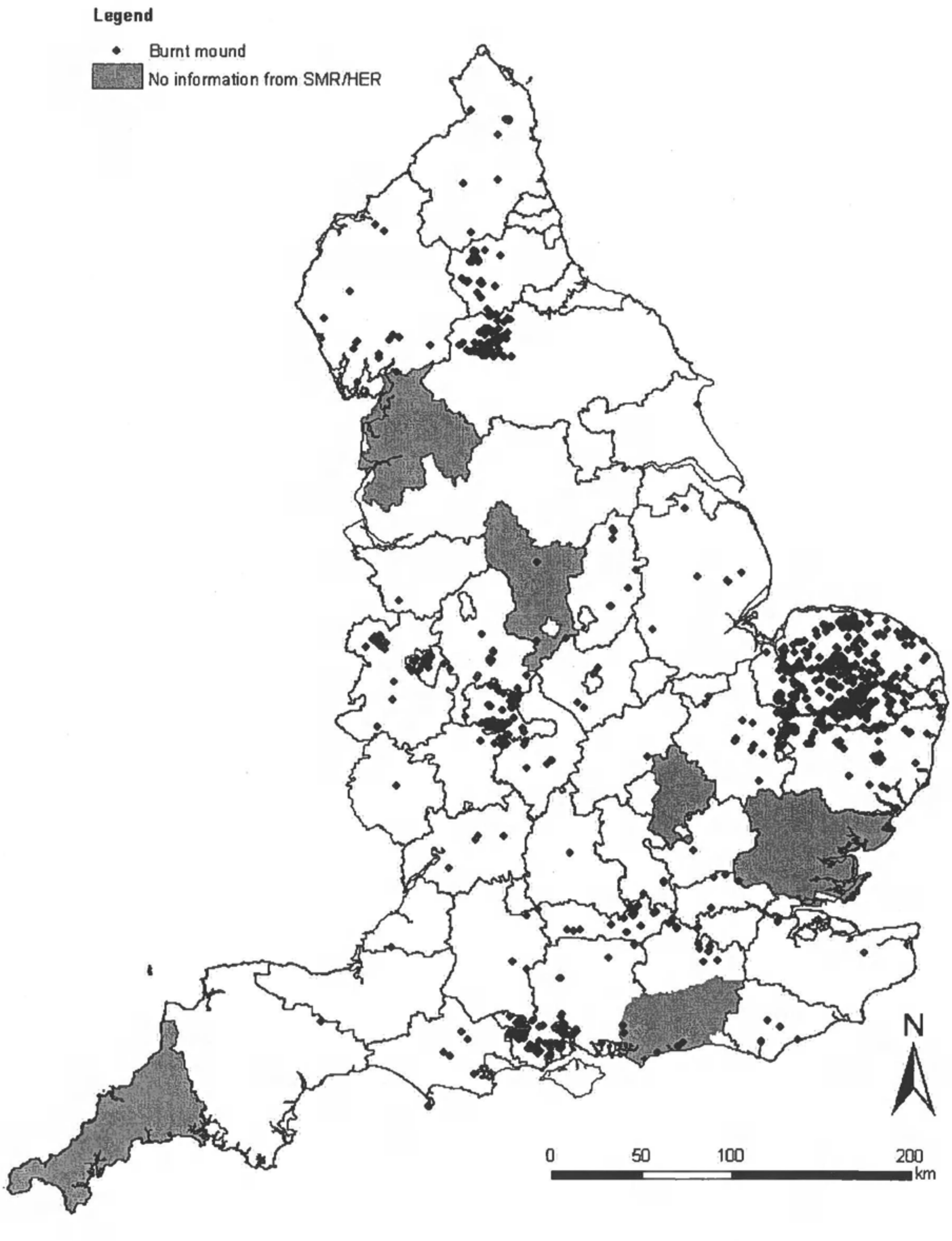
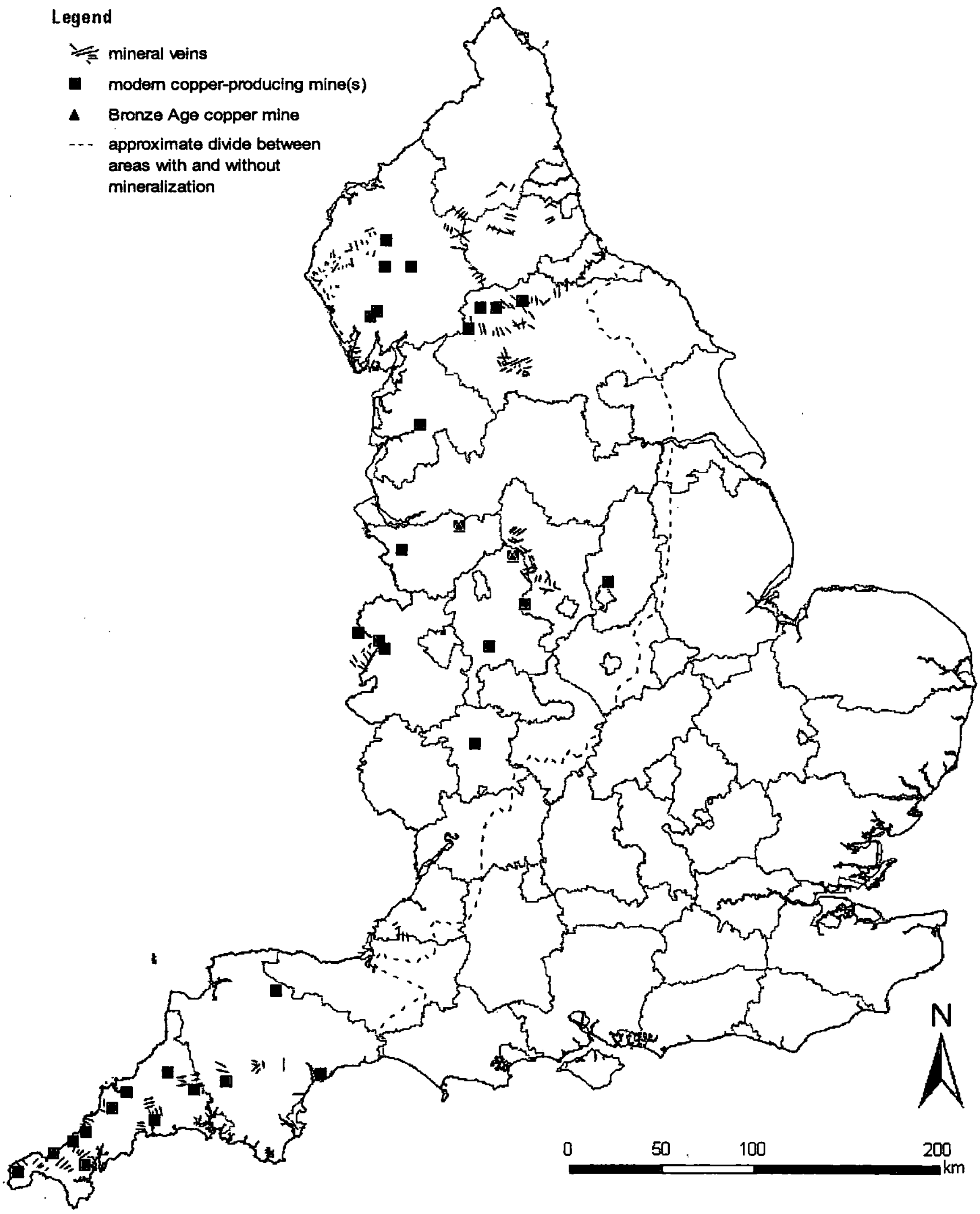


Figure 5-2b: Mineral Veins and Copper Sources in England



these also have mines from which some copper has been obtained in modern times. Alderley Edge mine in Cheshire, which was worked in the Bronze Age, is not in any of these areas of mineralization, but is located along a techtonic fault line, one of several which run roughly north-south in this general area, which has allowed minerals to accumulate there (Vokes, F. 1978, 10). The same is probably the case with several other mines in Cheshire, Staffordshire and possibly Worcestershire.

Map Comparison and Interpretation

Of the four areas in England where burnt mounds are concentrated, two appear to be possibly related to mining areas and two do not. In northern England the burnt mound concentrations are fairly close to the mining areas and mineral veins of the Northern Pennines and the Lake District. Lead has been the principal metal mined in the Northern Pennines in modern times, but some copper has been obtained from some of those mines, and there have been copper mines in the Lake District and the Richmond area of Yorkshire.

The Birmingham area and its burnt mound-abundant environs are virtually encircled by a ring of mines related to the Southern Pennines on the east, the West Shropshire mineral veins on the west, and the mines probably along techtonic lines filling in other spaces between. Given the presence of Alderley Edge, it is rather surprising that there are so few burnt mounds in Cheshire. The wetlands of Cheshire were surveyed by the same researcher (Mark Leah) who found many of the burnt mounds known in the Shropshire and Staffordshire wetlands, so the difference can hardly be a matter of differing levels of research or a different type of terrain.

Especially in the Birmingham area, and to a lesser extent in northern England, although the burnt mound concentrations and copper sources may look fairly close on the map, because the map scale is so small there may in some cases be several tens of kilometres between them. In these cases it is probably unlikely that ore was carried from the sources to the mounds.

On the other hand, the East Anglia and Hampshire concentrations of burnt mounds are located in the part of England where there is essentially no mineralization. Most likely they were not used for copper processing. If they were, the copper ore would have had to be brought from some quite distant place. Though unlikely, this might have been barely possible, as both areas are coastal, and, as previously mentioned, it was probably easier to transport goods via water than land in the Bronze

Age. The burnt mounds of Hampshire are clustered near the mouth of the River Avon, which must have been an important waterway in the Bronze Age, since it served the great Stonehenge ritual area. The bluestones, for example, might have been transported by boat from Wales, around Cornwall and up the Avon to Stonehenge. A similar route could have brought both copper and tin to the burnt mound sites of Hampshire. The Dover boat, dating to around 1550 BC, is thought most likely to have been a coastal vessel (Crumlin-Pederson 2006, 58 and 66), so boats of this type might have made such journeys.

As for East Anglia, quite a few of the burnt mounds clustered around the Wissey Embayment have dates in the earliest burnt mound period, which suggests that people from the continent may have travelled there to establish those sites. If so, and their purpose was metal-making, they might have brought raw materials with them, attracted by the combination of East Anglia's suitably wet environment and its flint mines. In support of this possibility is a statement from Colin Pendleton (pers. comm.): "I recorded over 11,000 items [of Bronze Age metalwork] from Norfolk, Suffolk and Cambridgeshire in about 1990, so the amount present, and locally manufactured from material sourced elsewhere, in the Bronze Age must have been phenomenal!" However, it is also quite possible that much of this metalwork was brought into the region already manufactured elsewhere, in the same manner, for example, that finished Group VI stone axes were taken from the Lake District to Yorkshire and other parts of the British Isles (Cummins 1980, 45-60). It would have been much easier to move around finished metal products than ore.

There is one other anomaly in the English burnt mound-copper source situation. Copious amounts of copper were available in Cornwall, but no burnt mounds have been found there, and in neighbouring Devon, the only known burnt mounds are a pair on the eastern side, away from Cornwall. Simon Timberlake (2001, 182) has noted that, in spite of much searching, no evidence of Bronze Age copper mining has been found in this south-western England area. He suggests that the people of Bronze Age southwest England may have been discouraged from mining copper, in order to concentrate all effort on tin production, tin being much more scarce in the British Isles generally, and therefore more valuable. The law of supply and demand would have been operative, probably causing most people in this area to opt in favour of producing tin rather than copper. It is also possible that massive modern mining has obliterated every trace of ancient copper mining, but if

Timberlake is right about the reason for the lack of Bronze Age copper mining evidence, it could also explain why no burnt mounds are found there, if burnt mound sites were in fact used for copper-processing. Tin is much easier to smelt and probably would not have left tell-tale mounds of burnt stone (Timberlake 2003, 34-5).

The Distribution of Burnt Mounds in Wales (Figure 5-3a)

In Wales burnt mound concentrations are found primarily throughout the western coastal counties and the areas immediately adjacent to them on the north and south. An especially dense concentration is in Pembrokeshire and, to some extent, Carmarthenshire and Swansea. Burnt mounds are sparsely scattered over the inland region of Powys, while none have been found in the counties immediately adjacent to England on the north and south. The remainder of the southeastern coastal region has a few scattered burnt mounds, but since it is the most urbanized part of Wales, mounds which were once there may have disproportionately disappeared.

Copper Sources in Wales (Figure 5-3b)

All the major copper mining areas in Wales are in approximately the northern half of the nation. Important mines, both in the Bronze Age and modern times, are found at Parys Mountain on Anglesey and Great Orme on a promontory off Conwy. Gwynedd has two significant mining areas: the Harlech Dome, just to the southeast of the Lleyn Peninsula; and the area between that and Anglesey. Both of these are within Snowdonia National Park and are mountainous. An additional area, with multiple Bronze Age mines, as well as some modern ones, is the northern part of Ceredigion. On the border between Powys and Shropshire is the mineralization area, with some mines, already mentioned in the England section. Lastly, there is significant mineralization, and a few modern mines, in Flintshire and Denbighshire, northern coastal areas next to England.

In the south of Wales, only one small area of mineralization is shown, in Carmarthenshire, and only one mine, in Pembrokeshire.

Copper Concentrations in Stream Sediments in Wales (Figure 5-3c)

This alternative map (Webb 1976, 279), showing relative copper concentrations in analysed samples of stream sediments taken from all over Wales (excepting the areas which appear white), identifies most of the same copper-rich

Figure 5-3a: The Distribution of Burnt Mounds in Wales

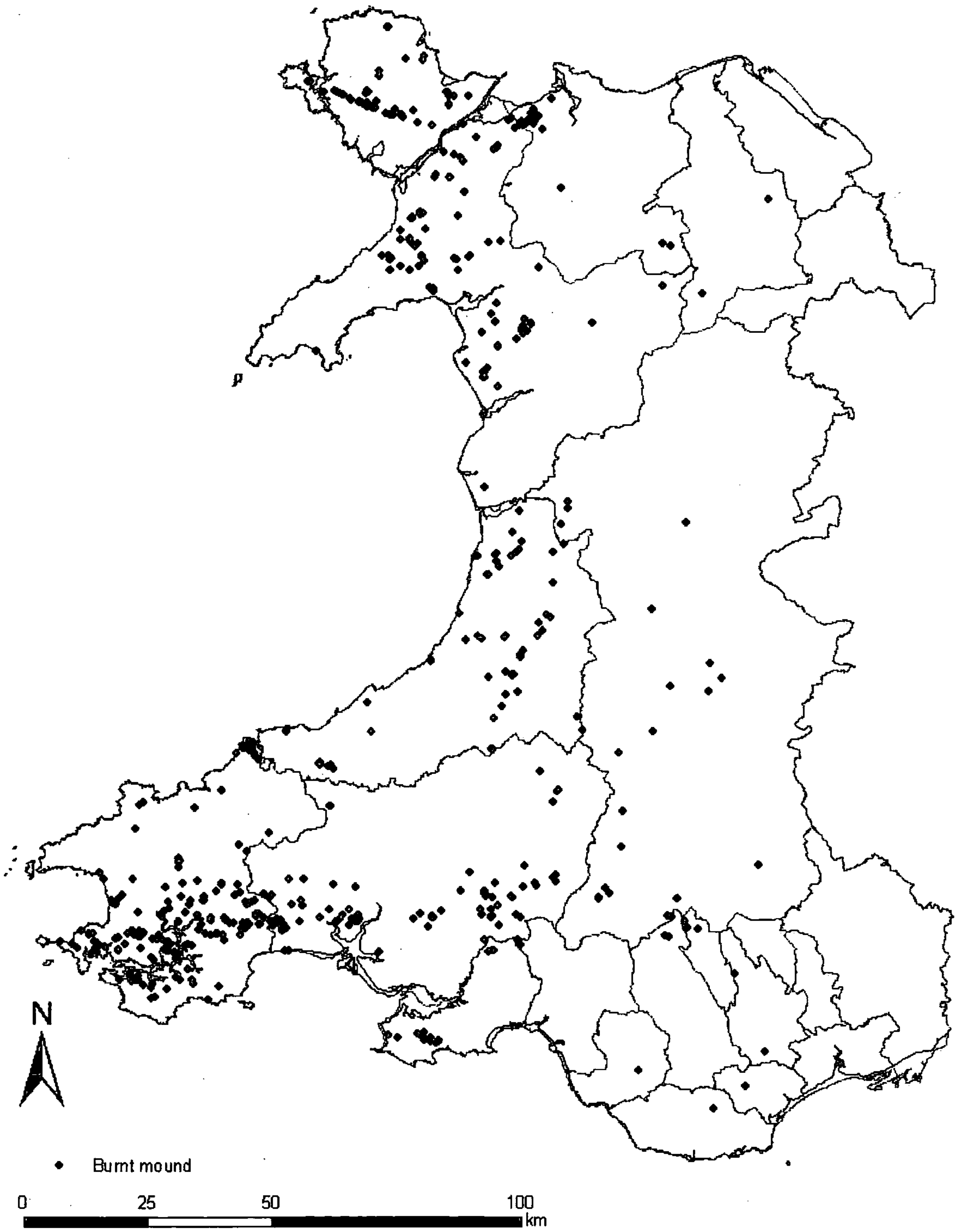


Figure 5-3b: Mineral Veins and Copper Sources in Wales

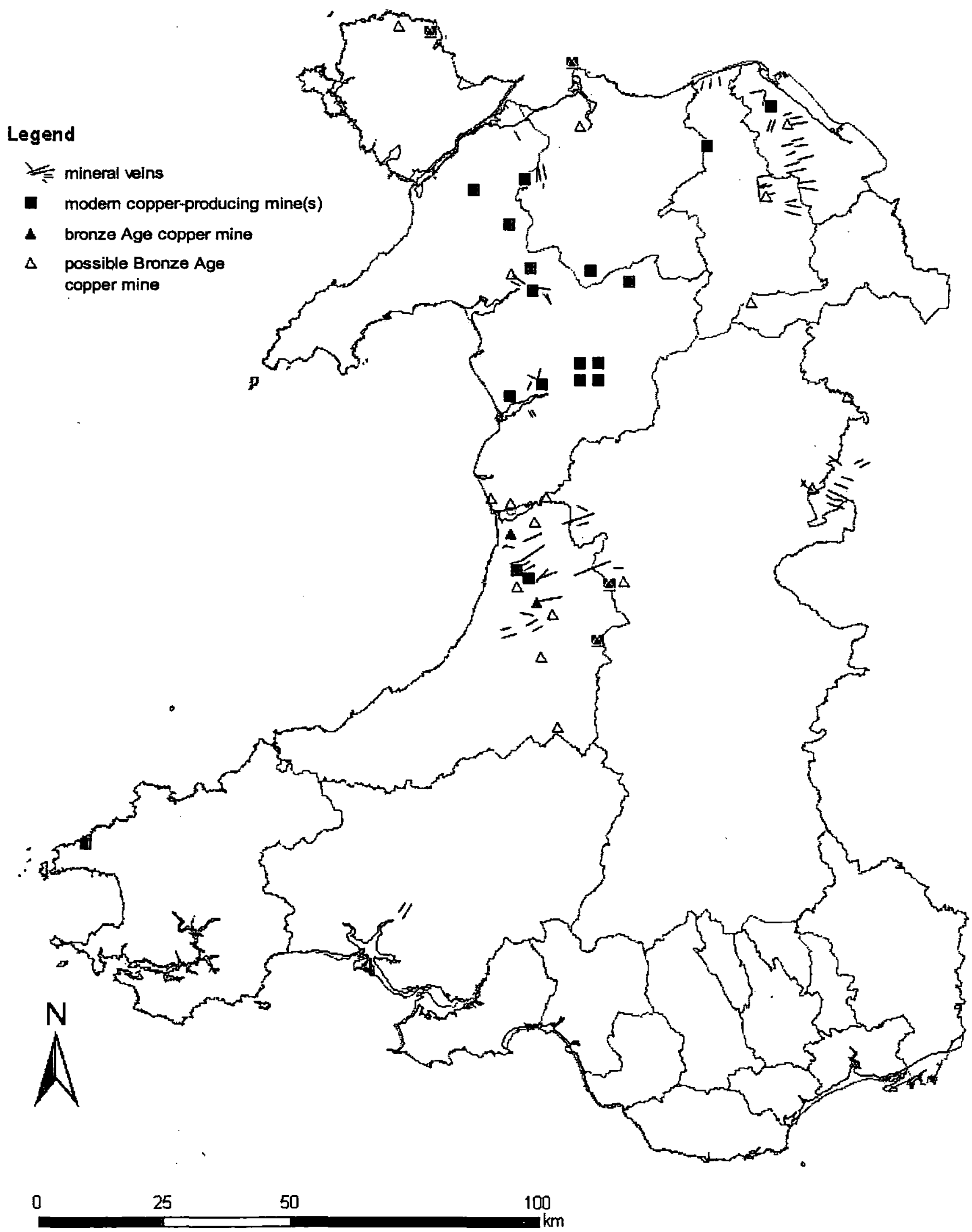
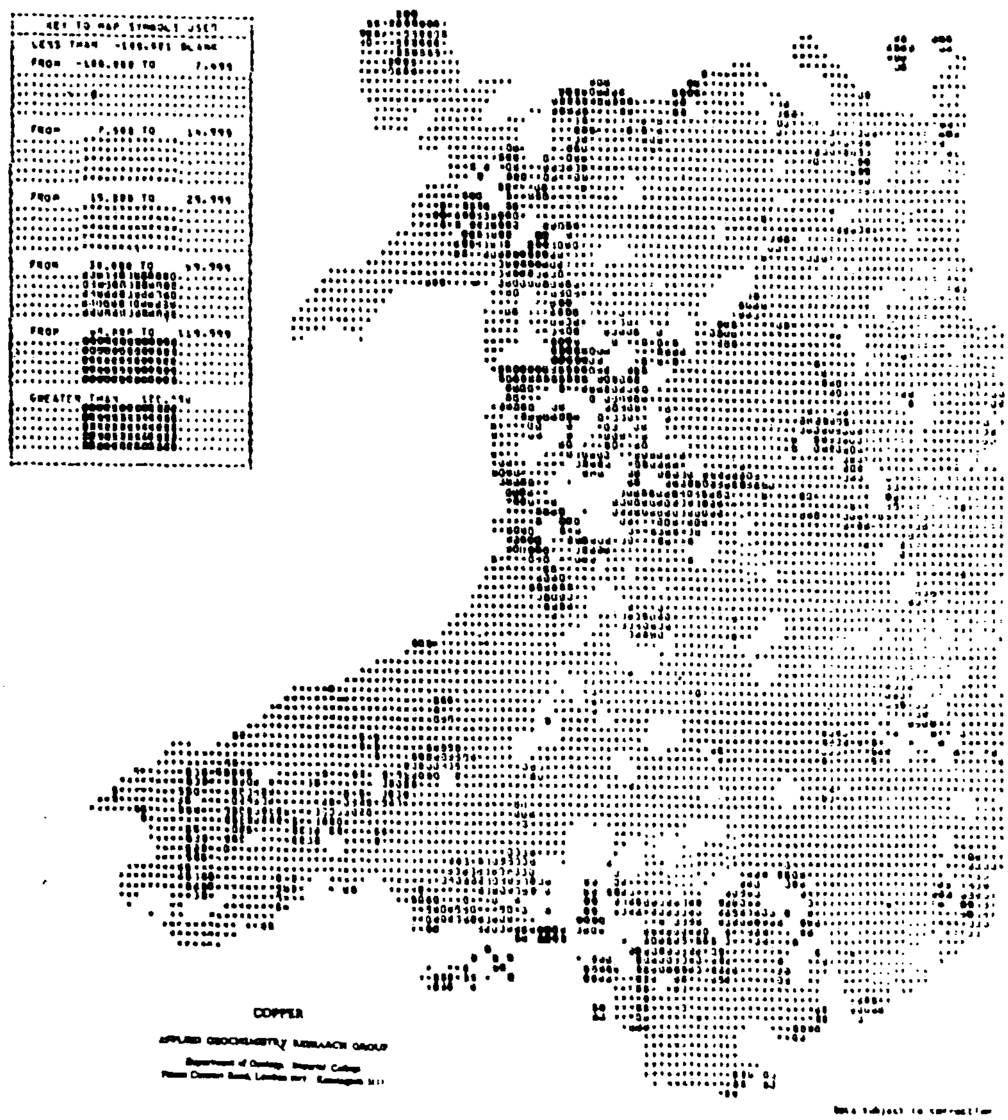


Figure 5-3c: Copper Concentrations in Stream Sediments in Wales



Source: J. Webb, in Briggs 1976, 279.

areas as Figure 5-3b, but, in addition, indicates some possibly significant copper concentrations in the south. Some of these may signify copper sources not important enough to interest modern mining companies, but could perhaps have supplied enough copper for Bronze Age operations. However, others may simply show areas of modern copper contamination. For example, most modern-era copper mines throughout Britain sent their output to Swansea for processing, so smelting waste from these operations must account for many of the high concentrations in that area.

Map Comparison and Interpretation

Except for the mineral area in Flintshire and Denbighshire, where there are few burnt mounds, the copper source areas shown in Figure 5-3b match quite well the burnt mound-abundant areas in Figure 5-3a for north Wales. There is a small but dense group of mounds not far from the Great Orme promontory, near the location of another, possible, BA mine, and a liberal scattering of burnt mounds on Anglesey. The surprisingly straight line of burnt mounds on Anglesey is the result of a watching brief and excavations along a pipeline, and suggests that more burnt mounds might be found if similar activity were carried out on either side of that line. There is a concentration of mounds in northwest Gwynedd, somewhat west of the Snowdonia mining area, at lower altitudes, as might be expected for copper processing sites; as well as a significant number of mounds in the Harlech Dome area. Burnt mounds are also spread rather thickly over somewhat more than the northern half of Ceredigion, roughly matching the area in which a number of copper mines have existed.

But the densest concentrations of burnt mounds in Wales are found in the south, in Pembrokeshire and Carmarthenshire, fairly close to the areas indicated with relatively high copper concentrations on the stream sediment map (Figure 5-3c).

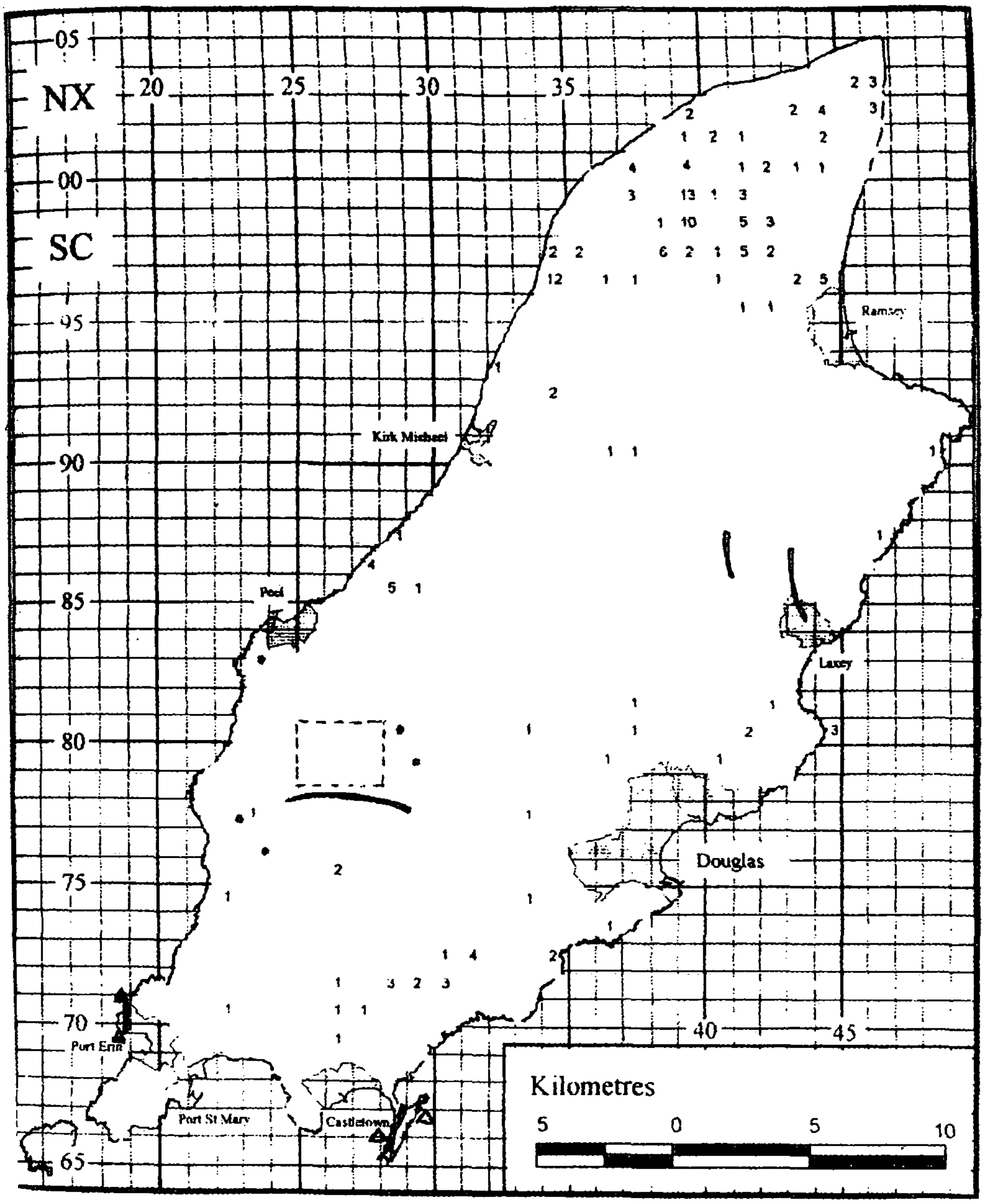
As to why there are more burnt mounds in the south than the north, where copper was more abundant, a major part of the answer is almost certainly the extensive surveys, specifically for burnt mounds, carried out early in the 20th century, only in the south, by Cantrill and Jones (1906 and 1911). They discovered and recorded almost 300 burnt mounds, many of which no longer exist today. Surveys in the north were only made much later, and none of similar scope. Other factors may also have contributed to the denser concentrations of burnt mounds shown in the south. Assuming that these concentrations were related to the presence of copper, the copper in the south may have been on or closer to the surface and so more readily observable, which would have been important for Bronze Age people lacking modern analytical techniques. Also, the densest concentrations of burnt mounds surround Milford Haven, which further underlines the possible importance of water-borne transport for their operation, as has been seen around the mouth of the River Avon, although this phenomenon could also be caused by siting burnt mounds along appropriate streams, of which there must have been many feeding into such major waterways.

The Isle of Man (Figure 5-4)

In the case of the Isle of Man, because both burnt mounds and copper sources appear on one map, they are discussed together. With over 170 burnt mounds known in an area smaller than most counties, the entire Isle of Man can be considered an area of dense burnt mound concentration; however, the mounds are unevenly distributed. By far the largest cluster spreads across the northern end of the island, but the nearest copper- producing mines are those at and near Laxey, at least 10 km away. There are a few other burnt mounds, scattered in various directions, somewhat closer to the Laxey mines, but none nearer than about 5 km. This distancing could well be caused by the mountainous terrain to the west of Laxey, culminating in Snaefell. The second most significant cluster of burnt mounds is toward the southeastern corner of the island, and near it on the Langness peninsula, there have been some modern copper mining attempts, as well as some evidence of possible Bronze Age mining. Bronze Age mining is more firmly established for a copper vein, also worked in modern times, running north and south through Bradda Head at Port Erin. There is no concentration of burnt mounds in its immediate vicinity, but the group, already mentioned, near Castletown and Langness, is not too far removed.

An interesting situation occurs near the one other mining area, Foxdale, in the mid-southern part of the island. In modern times these mines produced mainly lead, and copper was "rarely found and in very small quantities" (Dewey and Eastwood 1925, 78). However, G.W. Lamplugh, as quoted by Dewey and Eastwood (*ibid*, 89), said that the Beckwith mine at Foxdale "had a lode, with a copper-bearing branch, and strings of dark quartz containing steel-grained ore, and a little silvery fahl-ore" (fahl-ore being arsenic-containing copper ore). Very close to this mine is a concentration of around 20 burnt quartz mounds, which are considered to be in a different category from the usual burnt mounds, principally because they are not near a water source.

Figure 5-4: The Distribution of Burnt Mounds and Copper Mines on the Isle of Man



Legend

Numbers:	**burnt mounds in 1 km²**		**modern copper mine**
▲	**Bronze Age copper mine**		**quartz mound concentration**
△	**possible Bronze Age mine**	•	**individual quartz mound**

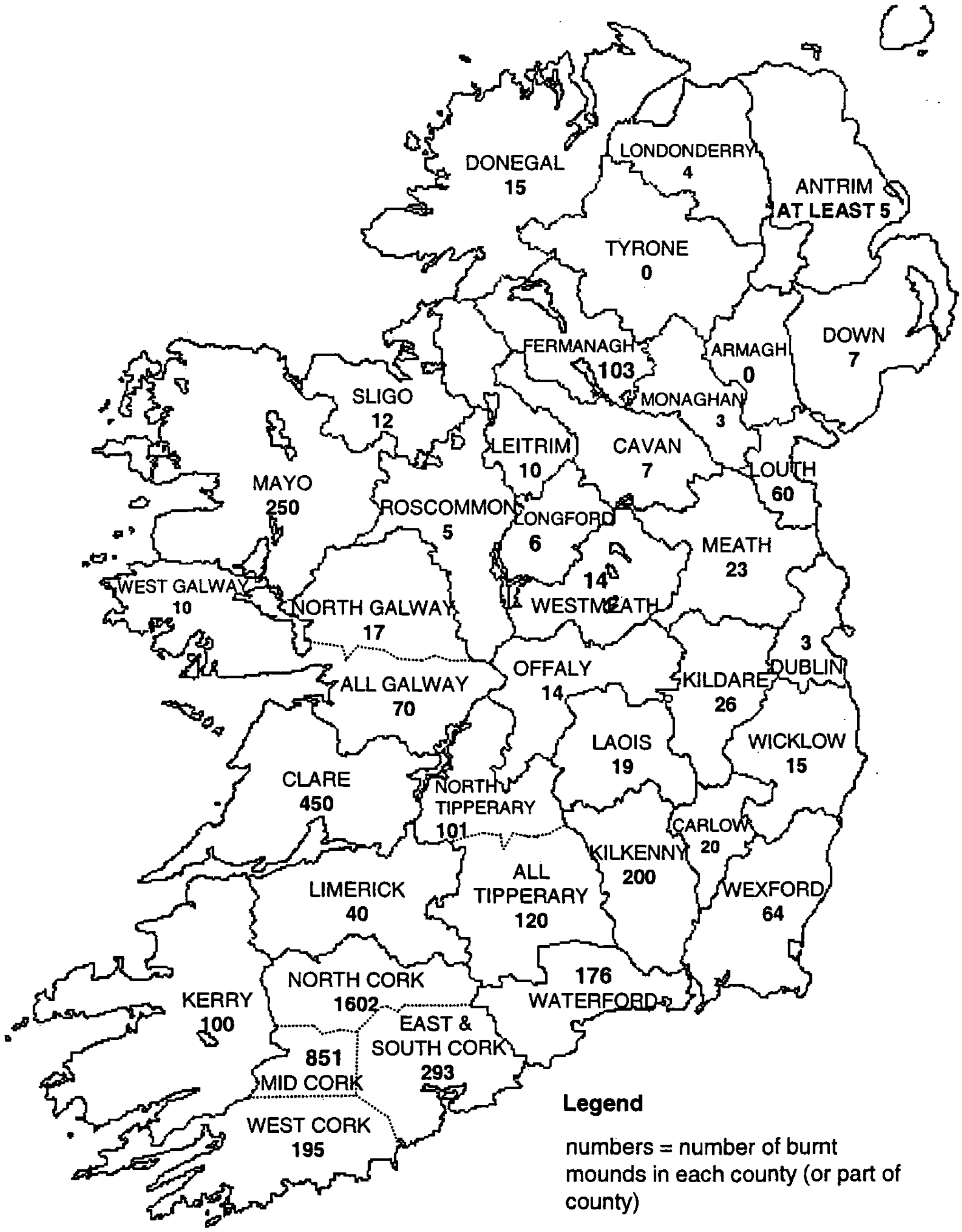
Map adapted from Garrad 1999, 77 and Pitts 1999, 63 & 72.
(Copper sources included in the list of copper source map sources.)

They also do not usually appear to have any associated trough. They do tend to have hearth areas, and artefacts found in them are, on the whole, ones which might be expected for Bronze Age copper-processing sites: coarse bucket-type Bronze Age pottery, hammerstones, slate discs and slabs, and querns (Pitts 1999, 64-73). From these characteristics and their position with respect to the Foxdale mines, it looks as if these sites might have been used primarily for crushing and sorting ore in the Bronze Age, and the hearths used perhaps for heating quartz chunks to facilitate removal of copper minerals within and/or subsequently roasting the concentrated ore. Whether or not they are classed as true burnt mounds, none of the ordinary burnt mound groupings on the Isle of Man is as closely associated with any mining area as are the quartz mounds.

The Distribution of Burnt Mounds in Ireland (Figure 5-5a)

As this map only shows numbers of burnt mounds known per county rather than exact locations, not as precise a comparison can be made with copper source locations as for other parts of the British Isles. Of the two types of sources used to produce the numbers shown, in general the numbers of burnt mounds described in archaeological inventories have been used, where possible, but these inventories are only available for about half the counties. Otherwise, numbers shown in Buckley's article (1991) are used; however, the round figures given for many of the counties suggest rough estimates, so this uncertainty in the numbers should be taken into consideration. What immediately stands out on the map is the huge number of burnt mounds in County Cork. Nearly 3,000 have been recorded there, more than half in the northern region. However, within this county the numbers are weighted in favour of the north and mid regions due to two master's theses devoted to finding burnt mounds in those areas, and also weighted against southwest Cork, because the only set of OS maps of the county which showed burnt mound locations did not cover most of southwest Cork (Power 1990, 14). Therefore, quite likely even more burnt mounds are or have been present in the coastal regions of this county than are indicated on the map. The other counties along the southern coast also have sizable numbers of burnt mounds. After the south coastal counties, the next largest concentration is in County Clare, followed by Counties Mayo, Kilkenny, Tipperary, and Fermanagh (in Northern Ireland).

Figure 5-5a: The Distribution of Burnt Mounds in Ireland (including Northern Ireland)



Copper Sources in Ireland (Figure 5-5b)

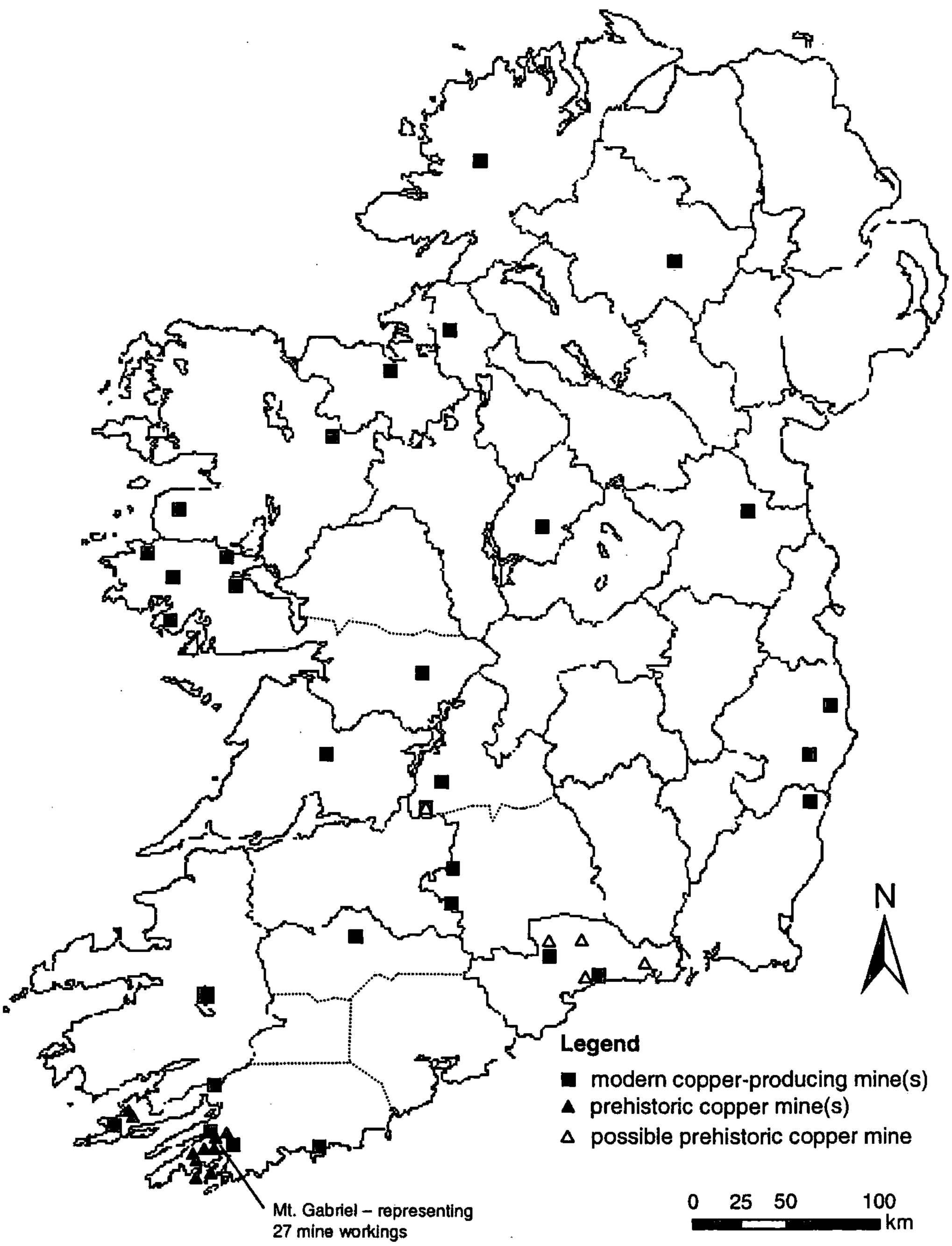
This map does not have mineral veins indicated; however, some idea of where they are can be acquired from descriptions in reference books. An unusual type of predominantly copper mineralization prevails in most of the Munster region (the south-western quarter of Ireland), which probably accounts for many of the mines there (Andrew 1993, 241). However, at least two types of mineralization are present in West Cork, resulting in the dense cluster of mines, both modern and prehistoric, found there. The mineral-containing metamorphic Caledonides extend from West Galway north-eastward through County Mayo and along the coastal areas to and beyond County Donegal (Williams and McArdle 1978, 321-2). The line of mines indicated on the map in this area probably relate to this mineralization, in which the incidence of copper is greater toward the Galway end, and that of lead in Donegal (*ibid*, 322). Two belts of paratechtonic Caledonides probably account for the mines in the southeast (Counties Waterford, Wexford, and Wicklow) and also the one in County Longford (*ibid*, 322).

Map Comparison and Interpretation

As with burnt mounds, the largest number of mines, both modern and ancient, is found in County Cork, including more than 30 workings in the Mt. Gabriel area dating to the Bronze Age. These mines are concentrated in the south-western coastal area of the county, while the burnt mounds appear to be most numerous in the north (but remember the caveat expressed above as to the relative numbers north to south), where there is only one modern copper mine. However, this is a mine where the principal product was copper, and, as mentioned above, there is a lot of copper generally throughout the Munster area, so it is conceivable that there might have been sufficient copper in northern Cork to support an exceptionally large copper-processing industry in the Bronze Age.

In County Clare, with the second largest burnt mound population, just one modern mine is shown, but Bronze Age people there might have also been working with ore from the mining areas close by in County Tipperary, where there is one possible Bronze Age mine. County Clare is also within the Munster area where copper is widespread, even if not everywhere in large enough quantities for modern mining. As County Tipperary, also within Munster, has several mining areas, it is not

Figure 5-5b: Copper Mines in Ireland (including Northern Ireland)



surprising that it has a relatively high concentration of burnt mounds. County Kerry is another Munster county with a sizable burnt mound population and contains the Ross Island Mine, worked in both earliest Bronze Age and modern times.

In other parts of the Republic of Ireland, County Kilkenny would be included in the same mineralization area as Waterford, Wexford and Wicklow, so there might have been sufficient copper there for Bronze Age, if not modern, production. County Mayo, with a large burnt mound population, has a few modern mines, and is located near the high-copper end along an important mineralization band.

There are also several counties where copper sources are present, but few burnt mounds. Wicklow has the Avoca copper mine, which has been important in modern times, but no large concentration of burnt mounds. West Galway, with several mines at the high copper end of a mineral band, also has few known burnt mounds.

Copper Concentrations in Soil in Northern Ireland (Figure 5-5c)

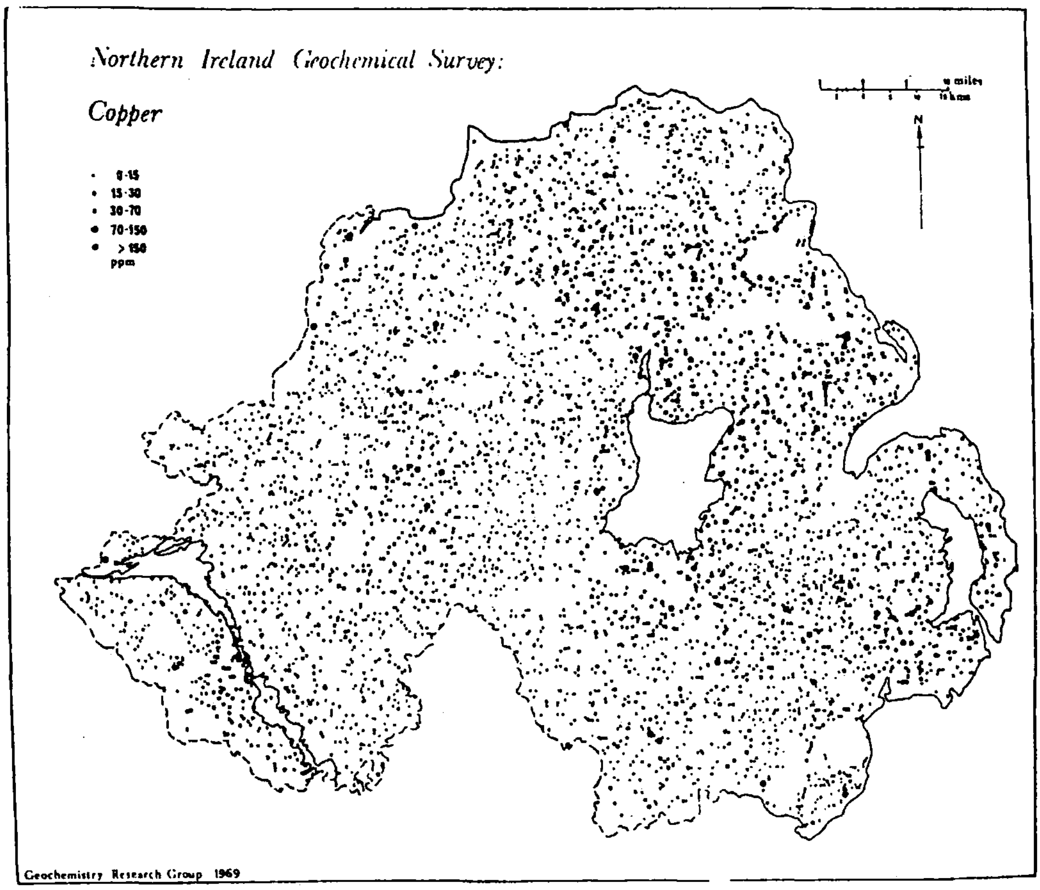
For Northern Ireland, another map, showing copper concentrations in soil samples collected throughout the region (Webb 1976, 276), has been included. It suggests a possible reason why County Fermanagh, alone among the counties of Northern Ireland, has a large number of burnt mounds. The edges of Lough Erne, which splits this county into halves, appear to have possibly the densest clusters of high copper soil concentrations anywhere in Northern Ireland. At least the north-western half of Fermanagh is probably affected by the mineral veins running from Galway through Donegal.

Other Possible Metallurgical Associations with Burnt Mounds

In the course of researching many surveys and listings of burnt mounds in order to produce this chapter's maps, a number of other possible or definite connections between burnt mounds and metal processing have emerged.

- **"Fire pits":** In two areas where significant amounts of copper have been mined in the modern era, Kirkcudbright in Scotland (Maynard 1993, 33-52) and Silvermines in Ireland (Farrelly and O'Brien 2002, 38-49), several sites have been found, called by their discoverers "fire pits" in the Scottish case and "burnt pits" in Ireland,. Each site consists of one or more pits "filled with

Figure 5-5c: Copper Concentrations in Soil in Northern Ireland

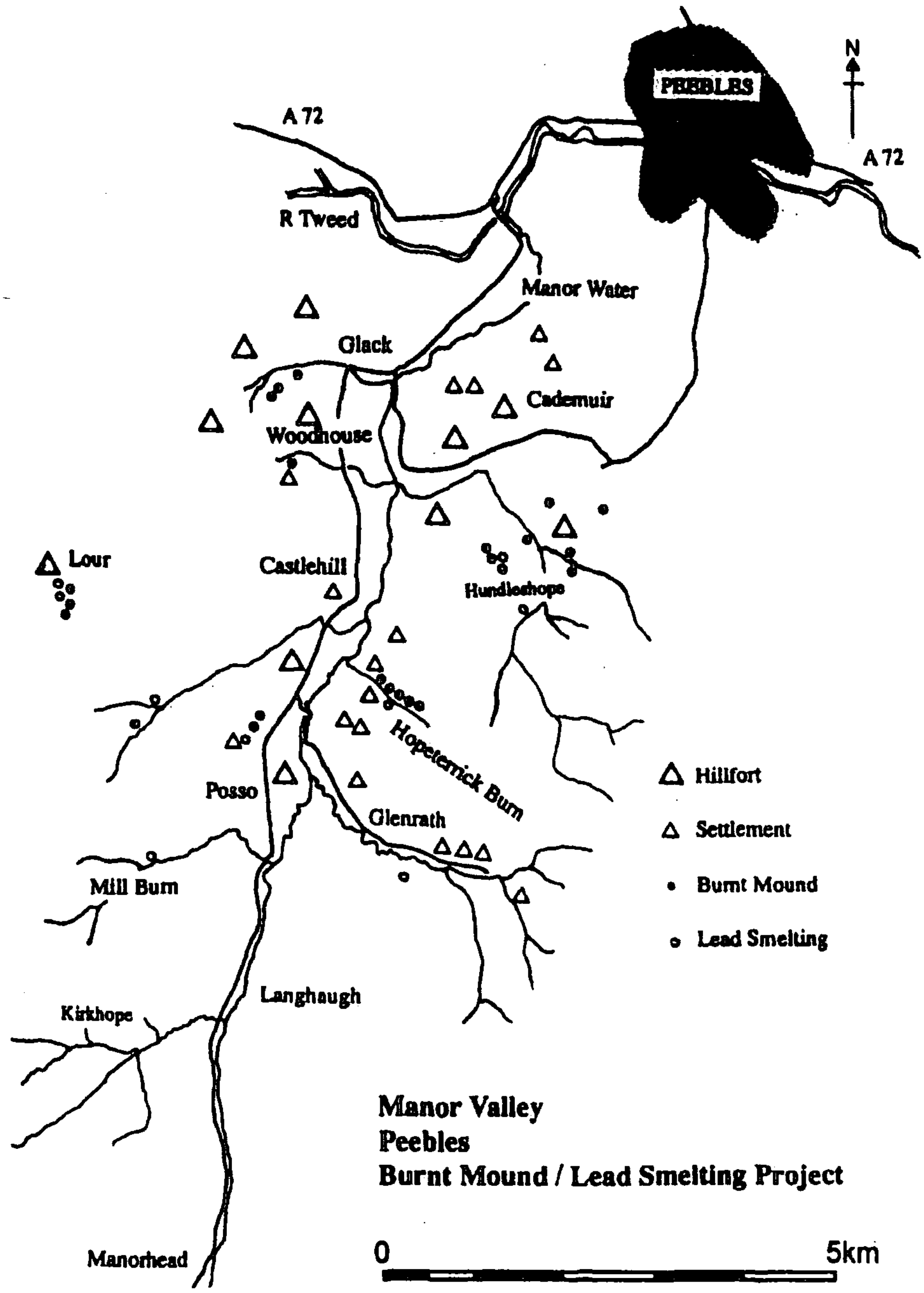


Source: J. Webb, in Briggs 1976, 276.

burnt stone and charcoal having the same characteristics as the material in a burnt mound" (Maynard 1993, 35), but without the mound. They are found in areas with large numbers of burnt mounds. Some in Ireland contain unspecified metal bits and slag. Their discoverers seem uncertain whether or not to categorize them as burnt mounds. These sites bring to mind both the "furnace pits" found at Ross Island and the earliest-dated group of burnt mound sites, described in Chapter 3, with multiple pits also filled with burnt mound material.

- **Iron smelting:** Several cases have been encountered where iron slag was found in otherwise ordinary burnt mound settings. A site at Crawcwellt, Gwynedd, Wales (Fairburn 2001, 102-3) is typical: from a group of 6 burnt mounds which were surveyed and considered to be of "late prehistoric" date, one mound, when augured, produced a piece of iron slag. In Southampton several fragments of slag were found at a probable burnt mound site (Southampton City Council SMR). At two Iron Age sites, Kebister in Shetland and Baleshare in North Uist (Barber 1990, 93-5), iron slag was found together with burnt mound material. These examples suggest the possibility that burnt mound technology may have had some carryover into the Iron Age, possibly with attempts being made to use it to produce the newly-introduced metal.
- **Charcoal pits:** In County Durham Tom Gledhill has found some pits used for making charcoal, assumed to be of mediaeval date, dug into burnt mounds which were presumably from the Bronze Age. He thinks the charcoal was being produced for the smelting of iron, but the pits were made in burnt mounds because they were the only dry spots in otherwise wet environments (T. Gledhill, pers. comm.).
- **Lead smelting:** In southern Scotland, where lead and copper are both found rather abundantly and often together, there are numerous examples of lead smelting sites in close association with groups of burnt mounds. At the largest of these, located near Peebles (Figure 5-6; Ward 1998, 81 and 1999, 77), with 7 lead smelting sites and 22 burnt mounds, two of the lead smelting sites and two burnt mounds have been radiocarbon-dated. The lead smelting sites

Figure 5-6: Burnt Mounds Associated with Lead Smelting Sites



Source: T. Ward 1998. Manor Valley. *Discovery & Excavation in Scotland,* 81.

proved to be mediaeval, but the burnt mounds dated to the Bronze Age. Why did mediaeval people choose to locate lead smelting operations close to burnt mounds? Was it simply because the environment chosen for burnt mounds in the Bronze Age also proved to be the right environment for lead smelting? Or could it have been because Bronze Age people had separated out and used copper minerals from the ore material with which they were mixed, and in the process had thrown away a significant amount of lead ore on their rubbish heaps? Could mediaeval people have been "mining" burnt mounds for lead? This idea is supported by W. Davies' description (Davies 1810, 41-2) of similar activity in his time in Wales: "the spots [at burnt mound sites] where the ores were deposited ready for the smelter's use, frequently contained fragments of lead ore in such quantities, as lately to have encouraged washers of ore to collect them. By this means, scores of tons have been recovered, in Flintshire, and at Dol y velin blwm, near Llanfyllin". What Davies described might also explain the current absence of burnt mounds in Flintshire, in spite of the presence of copper sources there. In any case, both the charcoal pit and lead smelting associations suggest that mediaeval people were "messing about" with or around burnt mounds, which offers a possible reason why a few burnt mounds produce puzzling mediaeval dates.

Conclusions

Was Walter Davies right? Throughout the British Isles, many burnt mound concentrations, perhaps a majority, are in broad, general areas where copper sources also exist. These include the Northern Isles and southernmost regions of Scotland; the northern Pennines and West Midlands of England; the north-western coastal counties (and possibly the south-western ones as well) of Wales; the Isle of Man; and Counties Cork, Waterford, Tipperary, Clare, Mayo and perhaps some others in Ireland. The question is whether the geographic relationship is close enough to imply a functional link.

One problem is that, in some of these cases, the distance from the copper source or sources to the nearest group of burnt mounds may often have been too great for ore to have been routinely carried overland. Ore would have made an exceptionally heavy load. The example of Timna in the Near East shows that ore was sometimes transported at least 3km (Rothenberg *et al.* 1978, 4-7) from the source to be processed and smelted, so perhaps the outer limit of distance, from one type of site to the other, might have been somewhere between 5 and 10km. This criterion, applied to the maps in this chapter, would almost certainly eliminate the West Midlands, and perhaps some other areas, as places where burnt mounds could have been ore-processing sites. (Where the ore could be moved by boat for all or part of the trip, as, for example, in the Northern Isles, there would have been no such limiting distance.)

However, it must be remembered that the data sets used to create the maps in this chapter are necessarily far from complete or fully accurate for the Bronze Age. During the Bronze Age there were certainly many more burnt mounds than now exist, and some that still exist are yet to be discovered. In addition, except for the locations where Bronze Age mines have been identified, the copper sources used at that time may have been somewhat differently placed, with some modern mining areas unused, and some deposits used which are too small or poor in quality for modern purposes, although all would have had to be where some copper was available.

There are other problems with the maps which need to be considered. While the burnt mound locations for Scotland, England, and Wales are accurately placed by GIS, the copper source locations on the corresponding maps are only estimations, and are shown only as symbols. The actual shape and extent of the mines is not clear, and mineral vein areas, as well, are shown symbolically, simply to indicate further general areas where there is a possibility of some copper having been available. Also, with the exception of the Isle of Man, the maps of other areas had to be created at such small scales that small approximations create large uncertainties in resulting distances.

It is also necessary to take account of the two cases where burnt mound concentrations are found with no copper sources anywhere near, and the one case (Cornwall and much of Devon) with plenty of copper but no burnt mounds. All of these are coastal locations, to or from which copper ore could have been transported, but this seems an unlikely possibility, given the many places where copper was available. The most likely explanation is that burnt mound sites, in these places at least, did not function as copper-processing centres. Coastal locations would have been useful for any industrial process which prepared goods to be traded to distant places.

Taking all the limiting factors into consideration, these maps can do little more than suggest those areas of the British Isles where there may be the greatest possibility of a functional relationship between burnt mounds and copper sources. Further research can then focus on each of these individual areas to find additional burnt mounds and Bronze Age mines, show their placements on larger scale maps, and decide whether the two types of sites are actually close enough to each other to have worked together in the production of copper.

Table 5-1: Burnt Mound Map Sources
(approximately in order of numbers of sites used)

For Scotland:	
Ferguson, L. 1990. A gazetteer of burnt mounds in Scotland. In V. Buckley, *Burnt Offerings*, Dublin: Wordwell Ltd., 179-94. *Discovery and Excavation in Scotland*, 1990 – 2005. Edinburgh: The Council for British Archaeology in Scotland. RCAHMS website: www.rcahms.gov.uk/search. Maynard, D. 1993. Burnt mounds around a pipeline in Dumfries and Galloway. *Dumfries and Galloway Natural History and Antiquarian Society*, 3rd Series, 68, 33-52. Banks, I. *et al.* 1999. Investigating burnt mounds in Clydesdale during motorway construction. *Glasgow Archaeological Journal* 21, 1-28.	
For England:	
Unitary authority SMR/HERs for:	
Bath & NE Somerset Birmingham Bristol City Buckinghamshire Cambridgeshire Cheshire Cumbria Devon Dorset Co. Durham East Sussex Gloucestershire Greater London Hampshire Herefordshire Hertfordshire Kent Leicestershire & Rutland Norfolk	Northamptonshire NE Lincolnshire North Lincolnshire North Yorkshire Northumberland Nottinghamshire Oxfordshire Shropshire & Telford & Wrekin South Gloucestershire Solihull Somerset Staffordshire Suffolk Surrey Warwickshire Wiltshire Worcestershire York City
Archaeological units, each managing an SMR/HER for several small areas: Berkshire Archaeology Black Country Archaeological Service Humber Archaeological Partnership	

Tees Archaeology
Tyne and Wear Specialist Conservation Team
West Yorkshire Archaeology Advisory Service

English Heritage Pastscape website: www.pastscape.org.

Laurie, T. 2003. Gazetteer of burnt mound sites: Wensleydale, Swaledale and Teesdale. In T. Manby *et al.*, *The Archaeology of Yorkshire*, Leeds: Yorkshire Archaeological Society, 250-3.

Leah, M. *et al.* 1998. *The Wetlands of Shropshire and Staffordshire.* Lancaster: North West Wetlands Survey, 137-85.

Hodder, M.A. and Welch, C. 1990. Burnt mounds in the South Staffordshire area. *Staffordshire Archaeological Studies*, New Series 4, 15-24.

Beamish, M. 2001. Neolithic and Bronze Age activity on the Trent flood plain. *Derbyshire Archaeological Journal* 121, 9 -16.

Pasmore, A. and Pallister, J. 1967. Boiling mounds in the New Forest. *Hampshire Field Club* 24, 14-9.

For Wales:

Welsh Archaeological Trusts:

Cambria Archaeology SMR
Clwyd Powys Archaeological Trust SMR
Glamorgan-Gwent Archaeological Trust SMR (Higginbottom, G. forthcoming publication. *Burnt Mounds of Southeast Wales.*)
Gwynedd Archaeological Trust HER

Maynard, D. (forthcoming publication). Chapter 7: The burnt mounds. In A. Davidson (ed.), *Excavations on Anglesey 1999: The Anglesey DBFO Scheme (Part II – Figures and Tables).*

RCAHMW Coflein website: www.coflein.gov.uk

White, R. 1977. Rhosgoch to Stanlow Shell Oil pipeline. *Bulletin of the Board of Celtic Studies* 27(3), 463-93.

For Republic of Ireland:

Archaeological Inventories (Dublin: Government of Ireland) of:

County Carlow: Brindley, A. and Kilfeather, A. 1993, 17-8.
County Cavan: O'Donovan, P. 1995, 31-2.
County Cork – West: Power, D. *et al.* 1992, 79-95.
" " - East and South: Power, D. *et al.* 1994, 24-49.
" " - Mid: Power, D. *et al.* 1977, 75-145.
" " - North: Power, D. *et al.* 2000, 43-175.

County Galway – West: Gosling, P. 1993, 26-7.
" " - North: Alcock, O. *et al.* 1999, 20-2.
County Laois: Sweetman, P. *et al.* 1995, 12-3.
County Leitrim: Moore, M. 2003, 26-7.
County Louth: Buckley, V. 1986, 24.
County Meath: Moore, M. 1987, 45.
County Monaghan: Brindley, A. 1986, 12.
County Offaly: O'Brien, C. and Sweetman, P. 1997, 14-6.
County Tipperary – North: Farrelly, J. and O'Brien, C. 2002, 38-49.
County Waterford: Moore, M. 1999, 37-49.
County Wexford: Moore, M. 1996, 19-23.
County Wicklow: Grogan, E. and Kilfeather, A. 1997, 37-8.

Buckley, V. 1991. Irish fulachta fiadh: an overview. In M.A. Hodder and L. Barfield (eds.), *Burnt Mounds and Hot Stone Technology.* Sandwell: Sandwell Metropolitan Borough Council, 4.

For Northern Ireland:

Northern Ireland SMR, Environment and Heritage Service website: www.ehsni.gov.uk.

Archaeology Data Service website: ads.ahds.ac.uk/catalogue

For Isle of Man:

Garrad, L. 1999. Field walker's records of burnt mounds in the Isle of Man. In P.J. Davey (ed.), *Recent Archaeological Research on the Isle of Man.* BAR British Series 278, 75-80.

Pitts, M. 1999. Quartz mounds: a preliminary assessment. In P.J. Davey (ed.), *Recent Archaeological Research on the Isle of Man.* BAR British Series 278, 63-74.

Table 5-2: Copper Source Map Sources
(in alphabetical order)

Andrew, C. 1993. Mineralization in the Irish midlands. In R. Pattrick and D. Polya, *Mineralization in the British Isles*. London: Chapman and Hall, 209.

Cunliffe, B. *et al.* 2001. *The Penguin Atlas of British and Irish History*. London: Penguin Books, 27.

Dewey, H. 1923. *Copper Ores of Cornwall and Devon*. Special Reports on the Mineral Resources of Great Britain, Vol. XXVII. London: His Majesty's Stationery Office.

Dewey, H. and Eastwood, T. 1925. *Copper Ores of the Midlands, Wales, the Lake District and the Isle of Man*. Special Reports on the Mineral Resources of Great Britain, Vol. XXX. London: His Majesty's Stationery Office.

Doonan, R. and Eley, T. 1999. The Langness ancient mining survey. In T. Darvill, *Billown Neolithic Landscape Project, Isle of Man*, Fifth Report 1999, Bournemouth and Douglas: Bournemouth University School of Conservation Sciences, 45-53.

Doonan, R. and Hunt, A. 1998. Assessing the research potential for prehistoric mining and metallurgy on the Isle of Man. In T. Darvill, *Billown Neolithic Landscape Project, Isle of Man*, Fourth Report 1998, Bournemouth and Douglas: Bournemouth University School of Conservation Sciences, 64-9.

Dunham, K. *et al.* 1978. United Kingdom. In S. Bowie *et al.* (eds.), *Mineral Deposits of Europe, Vol. 1: Northwest Europe*. London: The Institution of Mining and Metallurgy and The Mineralogy Society, 263-317.

Farrelly, J. and O'Brien, C. 2002. *Archaeological Inventory of North Tipperary*. Dublin: Government of Ireland, 350.

Hall, A. 1993. Stratiform mineralization in the Dalradian of Scotland. In R. Pattrick and D. Polya, *Mineralization in the British Isles*. London: Chapman and Hall, 38-101.

Moore, M. 1999. *Archaeological Inventory of Waterford*. Dublin: Government of Ireland, 60.

Ovrevik, S. 1985. The 2nd millennium and after. In C. Renfrew (ed.), *The Prehistory of Orkney*. Edinburgh: University of Edinburgh Press, 132.

Power, D. *et al.* 1992. *Archaeological Inventory of County Cork, Volume 1: West Cork*. Dublin: Government of Ireland, 72-8.

Rice, C. 1993. Mineralization associated with Caledonian intrusive activity. In R. Pattrick and D. Polya, *Mineralization in the British Isles*. London: Chapman and Hall, 102-86.

Timberlake, S. 2001. Mining and prospection for metals in Early Bronze Age Britain – making claims within the archaeological landscape. In J. Brück (ed.), *Bronze Age Landscapes*, Oxford: Oxbow Books, 180.

Timberlake, S. 2003. Early mining research in Britain: the developments of the last ten years. In P. Craddock and J. Lang (eds.), *Mining and Metal Production through the Ages*, London: The British Museum Press, 21-42.

Webb, J. (unpublished data), from Briggs, C. 1976. Notes on the distribution of some raw materials in later prehistoric Britain. In C. Burgess and R. Miket, *Settlement and Economy in the 3rd and 2nd Millennia BC*, BAR British Series 33, 267-82.

Williams, C. and McArdle, P. 1978. Ireland. In S. Bowie *et al.* (eds.), *Mineral Deposits of Europe, Vol. 1: Northwest Europe.* London: The Institution of Mining and Metallurgy and The Mineralogy Society, 319-45.

Wilson, G. 1921. *The Lead, Zinc, Copper, and Nickel Ores of Scotland.* Special Reports on the Mineral Resources of Great Britain, Vol. XVII. Edinburgh: Morrison and Gibb, Ltd., frontispiece map, 45, 69, 75, 77, 115, and 147-51.

Chapter 6

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Combining knowledge of early metallurgy, as developed in Chapter 2, with the general characteristics of burnt mounds, from Chapter 3, a hypothetical model describing how burnt mound sites might have worked as copper processing places can be constructed.

A Hypothetical Model of Burnt Mound Sites as Copper Processing Places

The first step in the processing of copper ore at a typical burnt mound site might have been emptying the trough and refilling it with clean water, an action which would have been likely to be repeated several times in the course of the operation. Then, using flat stones or querns and pounders, the ore, which would have been transported to the site from a copper source such as a mine, would be crushed and sorted several times, with the pieces frequently rinsed in the trough or the stream to aid sorting (as in Doonan's roasting experiments), as they gradually became smaller and the selected ore more and more concentrated. In addition, any of several gravity separation techniques, all based on the relatively heavy weight of copper and the use of water to slow the settling of the lighter components of the crushed mixture (as described in Chapter 3), may have been carried out to help isolate the copper compounds present from the gangue. When the ore was sufficiently concentrated, before it could be heated, wood or peat for fuel would have been gathered, and eventually perhaps some wood would have been converted to charcoal, if smelting was planned.

Next, the hearth would have been prepared for either roasting or smelting, depending on the type of ore, or on whether the method being used combined these two procedures into one. If the next procedure was simply roasting, stones may first have been scattered on the surface of the hearth or built into a platform on it (as suggested by the broken slag cakes in the Mühlbach example, or the platform built by Doonan in two of his experiments) to increase the exposure of the ore to the air. Probably a fire would then have been built there to preheat the hearth, and when it was ready, the concentrated ore and more fuel for the fire would have been added, with the burning continuing until all the copper minerals were thought to have been converted to the more easily smelted copper oxides. This point might have been determined by the absence of any further sulphur dioxide odour.

The processing at the burnt mound site might have stopped at this point with the concentrated and roasted ore passed on to some other place for smelting, or the process might have continued at the burnt mound site with the prepared ore smelted there. As to the smelting method, during the Neolithic-to-Bronze Age transition period there may have been two or more contending technologies for smelting copper in the British Isles. One was probably a pit-based method, as seen at Ross Island (and quite possibly also near Silvermines in Ireland and in southwest Scotland), likely imported into the British Isles along the Atlantic coastal route from perhaps Iberia or Brittany. However, another technique may have developed indigenously, either in Britain or Scandinavia, in which the pit was, in effect, turned upside down on an essentially flat piece of ground, with the inverted pit created by building a temporary stone structure or covering over the ore for each heating. The multiple pits at burnt mound sites from the earliest period seem rather similar to the furnace pits at Ross Island in terms of size, irregular shape, and even general lack of burning on the sides, which could be due to the contents having been dug out after each use, or to a stone lining. The multiple-pit sites might be examples of an intermediate stage between the two methodologies in which pits may have been used as hearths, but with large amounts of burnt stone also present. Among modern experiments on early smelting methods, the inverted-pit type may have been best recreated by Coghlan (1940, 49-65) when he inverted a porous pottery vessel over copper ore to be smelted and claimed to have produced copper metal at a relatively low temperature (700-800°C) and without forced air. If burnt mound sites were indeed copper smelting places, the huge numbers of them, especially of those in operation during their "classic" period covering the Early Bronze Age, suggest that the inverted-pit method generally prevailed over its simple-pit competition in the most northerly parts of Europe. The EBA was also the period during which most of the known Bronze Age copper mines in the British Isles were being worked; only Great Orme seems to have continued in operation much longer.

The details of a hypothetical smelting procedure are quite unclear. The prepared ore would have been placed in the hearth, perhaps on a flat stone or some sort of crucible and perhaps with a flux and/or fuel added. Then stones would have been placed over it in such a way as to have largely prevented air from reaching it, possibly using clay to help hold the structure together and make it more air-tight. Finally, the stone structure would have been well covered with fuel, which would then have been lit, with more fuel continually added until the process was judged to be complete.

When the roasting and/or smelting was finished, the entire mass within the hearth would have been pushed or shovelled into the water-filled trough, facilitated by the location of the hearth, in most cases close to, and often slightly above, the short side of the trough away from the stream. This procedure would have been carried out to cool all the materials and to help separate them. Remains of the fuel would float and could be removed first, and then the stones. Then the water could be successively stirred up and portions of it removed. Most of the copper should be found at the bottom, but probably everything else removed would have been carefully checked for copper or copper-bearing minerals remaining on or in it, before being thrown on the accumulating refuse heap. Any remaining unreduced copper minerals found would be added to later smeltings.

The Feasibility of the Model

How likely is it that the above hypothetical model, or something roughly similar to it, represents what actually happened at burnt mound sites? On the positive side, plausible usages are found in it for all the principal remains seen at burnt mound sites: the stream or other water source (also found at virtually all early metal processing sites worldwide), the trough, the hearth, the burnt stone, the charcoal, as well as the less-often-noted fired clay fragments, and perhaps some of the soil, which could have disintegrated from that clay. Some serious questions arise, however, especially regarding the possibility of smelting, and the hearth and heating conditions necessary for it.

The Question of Temperature

There is not much clear information as to what temperatures were actually reached in hearths at burnt mound sites. At the Sturdy Springs excavation, vitrified stone was found, which suggests a minimum temperature of at least 700°C, and more likely around 1000°C, but this is only one site, and in most other cases no vitrification has been reported. Also, it is not known whether wood or charcoal was used as the fuel at most sites, and this would make a large difference in the temperature which could be attained. At about 1m in diameter, most burnt mound hearths are too small to have contained bonfires, which would probably have been necessary to reach even the lowest temperatures used successfully in modern copper smelting experiments, if wood, and not charcoal, was the fuel. Budd found that copper produced in the solid state (at temperatures well below copper's melting point of 1083°C) was virtually impossible to separate out from the material surrounding it. Craddock assumes that charcoal was a possible fuel at this period, and if it was used, the melting point of copper could have been reached, so the problem of any copper formed being in the solid state would not have arisen. However, Budd's initial experiments showed that early copper containing arsenic must have been produced at temperatures below 900°C, because, otherwise, the arsenic would be present in higher concentration in the copper. (Budd has now rejected this finding, but he might have been right in the first place.) Since arsenical copper is most prominently known from the earliest period of copper production, it seems possible that the change in technology which appears to have occurred at the end of this period might have been a change in fuel for smelting from wood to charcoal, at the same time as a change away from arsenical ores due to the toxic fumes they produced when heated.

In modern experimental work, temperatures have ranged from the 700-800°C of Coghlan's experiment, through less than 900°C in Doonan's work (1994), to 1250°C in Rostoker *et al.*'s research (1989). When Craddock describes his theory of a simple, essentially slagless, poorly reducing Bronze Age smelting process, he does not specify the temperature level that would be required, presumably because this is not clearly known and would vary with the operational details, also not clearly known.

The Question of Reducing Capability

Changing copper from its combined forms in minerals to its metallic state (i.e., reduction) would require the immediate surroundings of the ore to be largely free of oxygen. If burnt mounds were used for smelting, this type of atmosphere is likely to have been created through use of the stones which give these sites their name. The stones are not slag, since if they were, they would long ago have been recognized as such. They also are not the remains of ore which have been separated from the copper minerals and discarded. If they were, they would show the marks of the breaking and crushing process, and would probably not be burnt. It seems the only position they could possibly fill in a smelting operation would be that of a means of preventing oxygen from reaching the prepared ore, but how effectively would they perform in this role? One piece of evidence is supplied in the micromorphology report which is part of the site report for Ceann nan Clachan (S. Carter, in Armit & Braby *et al.* 2002, 251). Among the 65 sites studied for Chapter 3, this is the only site report which contains a micromorphology analysis. About the material found in the principal hearth, Carter writes: "The dominance of carbonized [peat] fuel residues is striking and contrasts, for example, with the oxidized mineral ashes that constitute 251 [an early phase hearth] on the floor of Structure 1. This may be because the hearth in which the stones were heated may have had a relatively poor oxygen supply; possibly a large quantity of stones buried within a pile of peat fuel. It would therefore have generated more carbonized fuel residues than a small, well-tended cooking hearth." This explanation indicates that the heating process in this hearth was carried out in an oxygen-poor (i.e., somewhat reducing) atmosphere, and implies that stones may have helped to create that condition. More reports of this type are needed in order to know whether reducing conditions are found to be a usual condition in burnt mound hearths.

Since Craddock's theory, on the basis of solid evidence, postulates a poorly reducing technique, it would not have been necessary for the stones to have produced anything approaching a perfectly reducing atmosphere, but whether they could have created adequate reducing conditions for the production of some recoverable copper metal is at present unknown.

The Question of Forced Air

No tuyeres were found at any of the sample burnt mound sites studied in Chapter 3. Biodegradable materials such as reeds have been suggested as possible blowpipes, but it is hard to see how they could have been used close enough to the fire to increase the heat without being consumed by it. Although many burnt mounds are found on hillsides where winds can be strong, these locations usually appear to have been chosen primarily to make use of a nearby stream and/or spring. However, it is possible that this interpretation is not entirely correct. Perhaps burnt mounds tend to be near springs on hillsides because the issuing stream flows downward from the spring, and therefore the highest place on the hill at which the site could be located for the sake of strong winds, and also be close to the stream, would have been near the spring. On the other hand, it may have been possible, by using a technique similar to

Coghlan's, to produce copper without forced air, as he claimed. More research is needed on this matter.

The Lack of Metal-making Finds

At the 65 burnt mound sites studied in Chapter 3, only one piece each of amorphous copper, copper ore and copper slag were found; and no crucibles and only one fragment of a clay mould were identified (although both of these implement types have been found at some burnt mound sites in Sweden). Even the types of equipment needed for the ore-preparation stage, such as flat stones, querns, and pounding stones, were found in only a minority of cases. To some extent, these deficiencies can be explained. Residual copper, such as tiny bits of either beneficiated ore or smelted metal which had been overlooked by their producers, might well have mostly leached away; and, according to Craddock's theory, the process should have been largely slagless, with any slag formed unlikely to have the usual composition of fayalite and therefore difficult to identify. The lack of metallurgical equipment could be partly due to such important items having been removed from the sites when work finished. Also, especially in early excavations, oversights by researchers not specifically looking for such items could be partially responsible, but these reasons can hardly be the full explanation. The missing metalworking materials remain an argument against the use of burnt mound sites in the British Isles for copper processing.

Summary of Results from Chapter 3 Relating to Copper Production

It is possible to explain how each of the major features of a typical burnt mound site might have functioned as part of a copper processing site, but whether such functions would have been physically and chemically feasible, particularly for smelting, and given the almost total absence of metallurgical finds, is at present unknown and doubtful.

The Geochemical and Geographic Study Results

The geochemical and geographic studies reported in Chapters 4 and 5 have proved to have value primarily as initial, flawed, attempts to find connections between burnt mounds and copper production, from which some lessons can be learned and improved upon in future research along similar lines.

The EDXRF Analysis

No evidence of high copper concentrations was found in the three Sturdy Springs burnt mounds, except that which could be explained by bullet contamination. However, in the process, three valuable lessons were learned: 1) make as sure as possible in advance that modern contamination is absent from a chosen site; 2) expect some copper to have leached away relatively rapidly; and 3) do not expect measurable amounts of a valuable raw material or finished product necessarily to remain from a production process; in addition look for unwanted remains. The combined effect of the contamination, leaching, and removal from the site of any copper metal produced for use or trading might have eliminated any chance of finding clear evidence of copper itself remaining from the Bronze Age, even if the Sturdy Springs sites were copper processing places, something that is now still unknown. Any residual copper might more likely be detected with a portable XRF instrument placed against some of the important work surfaces, such as the trough, hearth, and old ground surface surrounding them.

The Comparison of Burnt Mound and Copper Source Locations

The geographic comparison produced ambiguous results. At least half the burnt mound concentrations appear from the maps to be rather close to copper sources, but several other factors need to be considered. The maximum distance ore could be expected to be carried overland to a processing place was probably only a few kilometres, not more than 10km at most. Because the scale of most of the maps is so small, a distance of 10km can look quite close, but may actually represent the outer limit of possible relationship. Furthermore, the positions shown for copper sources are inexact and do not indicate true shape and size of the copper deposits available. Finally, although the maps show general areas where copper would have been available for Bronze Age people to use, only in a few cases is it known that those sources were used in that period, and some other, lesser, sources not on the maps may have been used. All of these factors, taken together, render the results mainly useful for suggesting geographic areas where more intensive exploration and larger scale plotting could perhaps determine whether a relationship between the two types of sites actually exists in those localities.

At least three other areas, where burnt mound concentrations are found with no copper sources nearby, or vice versa, suggest that, even if some burnt mound sites were used for copper production, it is likely there were others used for different purposes. Most of these areas were bordered by coasts, where ore could have been transported more easily over long distances by boat than if carried overland on foot, and all bronze-producing sites, except in south-west England, would have required inward transport of tin, but still the shipping of copper ore is probably a remote possibility. Any industrial use for burnt mound sites would have benefited from coastal locations for the transport of its finished products, if not for its raw materials. Perhaps a more likely possible use for coastal burnt mounds would be steam-bending of timbers for the making of boats, as suggested by Keith Parfitt (2006), on the basis of experimentation by Gifford & Gifford (2004).

Overall, the balance of the evidence up to now suggests that the use of burnt mound sites for copper production activities is unlikely. However, very little research has focused on this possibility, there are many unknowns in the situation, and the attempts to find answers described in this paper have been flawed. Therefore, the question should not be considered closed, and more research should be encouraged.

Suggestions for Further Research

This research has produced no solid evidence that burnt mounds were copper-processing places. However, it has barely skimmed the surface of possible exploration and experimentation which could be carried out to test the theory. As this may be the first research project attempting to find a relationship between burnt mounds and copper production, there are numerous additional lines of inquiry which could be followed up. Therefore, some suggestions for further research are offered below, based on what has been learned in this project.

Experimental Reconstruction of Burnt Mound Sites as Copper Processing Places

This is the most crucially needed area of research, as it is the only way to prove definitively whether burnt mound sites could have functioned as copper production centres. It would require a long and extensive program of experimentation, as there are so many variables and unknowns. It could be based upon a combination of O'Kelly's (1954) methods of reconstructing a typical burnt mound site (in that case, to test the cooking possibility), Doonan's roasting experiments (1994), and Craddock and Timberlake's experiments on smelting in pit furnaces at Butser (2004). Many experiments would need to be carried out, in the course of which a number of different factors would be systematically varied; for example:

- fuel: wood (perhaps different species), peat, and charcoal
- different forms of cover provided by stones (from most open to air to most closed)
- different combinations of ore types (from single oxidic to single sulphidic, and various mixtures between)
- different hearth forms (simple open hearth vs. partially enclosed "furnace hearth" of LBA complex sites)
- different trough types (pit-only and different types of interior construction)

Other variations are also possible: adding various fluxes, adding tin, varying placement of fuel, etc.

Special Procedures during Burnt Mound Excavations

The above-recommended reconstruction experiments could show whether burnt mounds could have been smelting sites, and if so, what the optimum conditions might be, but, even if positive results were found, they would not prove that burnt mounds were actually used for this purpose. For that, it would be best to examine actual burnt mound sites in some new or little-used ways. The following procedures are recommended to be carried out during future burnt mound excavations:

<u>Measurement of burnt depth in hearth</u>: Perhaps because they usually seem so simple, hearths are often relatively neglected features during excavations. Yet it is from hearths that information on such vital points as the temperatures reached and the degree of oxidation or reduction achieved can be obtained. For example, in very few cases has the depth to which the ground has been burnt been measured at the place considered to be the hearth. This measurement, if routinely carried out at excavations, would at least provide relative data as to the intensity of the heat applied.

<u>Vitrification examination</u>: Vitrified material has not been noted in many burnt mound site reports, but was seen at the Sturdy Springs excavation on stone found beside the hearth. Is the general lack of indication of vitrification because no vitrification usually occurs at burnt mound sites, or because it has not been thought important enough to mention when it has occurred? The temperature range over which vitrification occurs is similar to the range of temperatures which have been used in experiments to identify ways in which early copper smelting may have been

carried out, so where vitrification is seen, plausible temperatures for copper production have been reached. Craddock (1995, 134) was able to estimate the length of time crucibles were maintained at high temperature from the depth to which they were vitrified. It seems possible there may be a relationship between vitrification and "cramp", which has been found at several sites and is probably soil fused by high heat. For all these related reasons, it is important that vitrification and cramp should be looked for, and reported when found, during burnt mound excavations.

Soil micromorphology: To judge whether smelting could have occurred, in addition to an estimation of temperature, it would be important to know whether oxidizing or reducing conditions had existed in the hearth. Soil micromorphology apparently can shed some light on this question, as seen in the Ceann nan Clachan report quoted above. In that case the report showed that at least partially reducing conditions had prevailed, which would have been required for smelting.

XRF analysis: Although this technique was unsuccessful in the present study, it would be worth trying in future research, making sure in advance that no obvious source of modern contamination is present. If possible, a portable XRF instrument should be used, with readings taken, not only from various contexts within the mound material, but also against the hearth, trough, and old ground surface. Obviously, special attention should be paid to copper and tin concentrations, but also to lead, especially in areas where lead and copper tend to be found together (southern Scotland, the Dales, some parts of Wales, etc.), as a pattern of high lead concentrations in the mound material, with raised copper levels found mainly at or below the old ground surface would suggest lead having been thrown away while copper was used in the operations at the site. In these areas it would also be useful to look for lead ore fragments (most likely, galena – PbS) in the mound material, the possibility of which is suggested both by W. Davies (1810, 41-2) and the lead smelting – burnt mound association found in southern Scotland (Ward 1998 & 1999).

Examination of mound material for other unwanted products of poorly reducing copper production: At early copper production sites in other parts of the world, such products as delafossite ($CuFeO_2$) and other oxides of copper and of other metals have been found, and they could be sought in burnt mound material. However, it seems uncertain whether they would still remain in the British Isles, even if they had initially been formed. The sites where they were found tended to be in hotter, drier climates (the Near East and southern Spain), where preservation would have been better, and the leaching effect less.

Exploration of a Possible Geographic Relationship between Burnt Mounds and Copper Sources

There appear to have been no specific attempts to locate burnt mounds in the immediate surroundings of either Bronze Age or modern copper mines. Those known burnt mounds which happen to be somewhat near copper sources were found for other reasons, often road or pipeline construction, or general surveys for all types of archaeological sites. Searches exclusively for burnt mounds which do turn up a number of them are not indications that they are found everywhere in equally large numbers. Usually such searches have been initiated because someone "stumbled upon" several burnt mounds in a certain area by accident, became interested, looked for more, and perhaps inspired others to do the same. This has been the case, for example, in the northern Pennines/Dales area (Laurie 2003); Anglesey (Maynard 1999 and forthcoming publication); the Birmingham area (Nixon 1980 and Barfield & Hodder 1981 & 1989); and the New Forest (Pasmore & Pallister 1967 and Pasmore 1984). Obviously several burnt mounds are much more likely to be discovered together by accident in areas where they exist in profusion than where they are scarce. The following types of research would help to clarify whether or not burnt mounds are in some cases clustered, apparently intentionally, close to copper sources.

<u>Systematic searches of the surroundings of Bronze Age and modern copper mines for burnt mounds</u>. Such searches should extend to a 5-10km radius around each mine in order to cover the distance within which it would probably have been practical to transport ore on foot. Mines are often located in quite rugged terrain which may be less-than-average likely to have been previously surveyed for archaeological sites.

<u>Searches of burnt mound cluster areas for minor copper sources which could have been used in the Bronze Age</u>. If any such sources are found, they should be carefully examined for any evidence to indicate that they were, in fact, used in the Bronze Age; such as hammerstones, markings typical of hammerstone use, or fire-setting. This type of search would require early mining expertise. Obviously, areas where the type of geology indicates that no copper could be present would not need to be searched.

If the above-suggested procedures are carried out, it may be possible someday to achieve greater certainty as to whether burnt mounds were part of the earliest phases of metal production in the British Isles.

The "Site and Process" Research Methodology

A distinctive feature of the research described in this dissertation is the parallel study of both the characteristics of a site type (burnt mounds) itself and of a process which has been suggested as its possible function (metal creation and working). This procedure makes possible direct comparison of what is typically found at the sites with what would likely be found as a result of the process in question. The more usual approach has been the study of either one or the other, the site type or the process, alone. A single study of the site type has to consider a wide range of interpretations and possible processes. This invariably leads to superficiality, and since this process is practised by every excavator who publishes their site, this leads to a repetition of analysis and ideas. (As examples, compare Bates and Wiltshire 1992, 408-11; Cressey and Strachan 2003, 200-2; and Moore and Wilson 1999, 233-5.) Burnt Mounds have long been thought likely to be cooking places and because cooking is a process generally well known, excavators have had a relatively clear idea of what to look for at the sites to test the theory. Consequently investigators have specifically looked for bones at those sites (Leah and Young 2001, 75-7 is one good example), and a few have also carried out analyses for phosphate (Banks 1999, 18) and lipids (Armit and Braby 2002, 246-7). The results so far in this case have been inconclusive. Similarly, though with some notable exceptions, studying a process, such as metal production, draws on a wealth of evidence from historic records, ethnographic sources and experimental archaeology, leading to a lack of focus on the actual surviving archaeological remains – which it is tempting to fit to the nearest ethnographic or historical model. Only when both the site type and the possible process are well understood can a program of testing and experimentation be devised which relates the two subjects under study, and which may be capable of determining whether the proposed function is likely to have been carried out at the sites in question.

This parallel "site and process" method could be taken much farther than it has been in the current project. It could also be applied to other suggested industrial uses of burnt mound sites, such as cloth fulling or dyeing, leather processing, wood shaping, etc. For this purpose the chapter on the characteristics of burnt mound sites included here could provide a useful base, augmented by additional site reports which become available in the future, all of which would then be compared with the detailed evidence and earliest known production methods of each process. The parallel method could also be useful in the case of other site types where the function has not been determined, but some possibilities have been suggested or can be generated.

Because burnt mounds are almost certainly the most numerous of all Bronze Age site types in the British Isles, a definitive determination of their function or functions would be a significant step in our knowledge of life in the Bronze Age, encouraging a burst of new research activity. Therefore, it is worthwhile to continue to search for the answer to the enigma posed by burnt mounds. The methodology used in this paper, which focuses on detailed assessment of both site evidence and process, may be a useful model for such a search.

Appendix 1

BURNT MOUND DATA SHEET

1. Burnt mound name: ______________________________

2. Location: A. England Wales Scotland Ireland Isle of Man

B. County or region: ______________________________

C. Town, etc.: ______________________________

D. OSM #: ______________________________

E. Terrain: ______________________________

1. Soil type______________________________
2. Rock type______________________________
3. Vegetation near mound______________________________

F. Excavation Extent: ______________________________

3. Water Source: A. Type: ______________________________

B. Location with respect to B.M.: ______________________________

C. Spring nearby? _____ D. Distance from B.M.: ______________________________

E. Other: ______________________________

4. Mound: A. Shape: ______________________________

B. Vegetation on mound: ______________________________

C. Size: 1. D: _________ 2. L: _________ 3. W: _________ 4. H _________

D. Stones: 1. Material: ______________________________

2. Size: ________________ 3. Condition: ________________

4. Density in matrix: ______________________________

E. Matrix composition:

1. Materials present 2. Relative Amounts 3. Descriptions

____

4. Analysis of mound material results: ______________________________

____

F. Other: ______________________________

5. Trough: A. Shape & description: ______________________________

B. Size: 1. D _______ 2. L _______ 3. W_______ 4. H (depth) _______

C. Construction material: ______________________________

____

D. Location with respect to:

1. stream: ______________________________

2. mound: ______________________________

3. hearth(s): ______________________________

E. Special features of bottom: 1. Slope: ______________________________

2. Other: ______________________________

F. Fill, residues, etc.: ______________________________

G. Automatic filling?: ______________________________

H. Other: ______________________________

6. Hearth: A. Shape & description: ______________________________

B. Size: 1. D _______ 2. L _______ 3. W_______ 4. H (depth) _______

C. Contents: ______________________________

D. Boundary: ______________________________

E. Heat degree indication?: ______________________________

F. Other: ______________________________

7. Finds:

1. Type & No.	2. Context	3. Description
A. Hammerstones & pounders		
B. Querns & lge., flat stones		
C. Pottery		
D. Bones		
E. Other		

8. Surrounding Area:

1. Type & No.	2. Location	3. Description
A. Post-holes		
B. Other structures excavated at site		
C. Known nearby contemporary sites		
D. Environmental evidence		
E. Other		

9. Dating:

A.: 1. C14 dates ______ 2. Material tested ______ 3. Context ______

B. Other dating methods:

10. Miscellaneous:

A: Details of additional structures incorporated into the mound

1. Shape and description: ______
2. Size: L:______ W:______ H:______ Other:______
3. Walls: W:______ Material: ______

______

4. Floor: ______
5. Subdivision? ______ 6. Method: ______
7. Details of each subdivision:______

______

8. Other:______

B: Other analyses and results: ______

______

C: Excavator's interpretation of function: ______

______

D: Other:

Appendix 2

Analytical detail for the Sturdy Springs sediment samples.

Sample preparation

The samples were dried and sieved to collect the < 2mm fraction. This was ground to a fine powder (,50 microns) and 0.5 grams were pressed into a 13mm diameter pellet ready for analysis.

Analytical Conditions

The analysis was undertaken by energy dispersive X-ray fluorescence (EDXRF) using an Oxford Instruments ED 2000 EDXRF spectrometer. Five instrumental settings were used to provide optimal conditions for the analysis of the following elements Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Mn, Fe, Ni, Cu, Zn, As, Pb, Sn and Sb. The parameters for the five conditions are defined by Oxford Instruments and are shown in table 1 below. All analysis was undertaken under vacuum. The analyses were calibrated using a full suite of single element standards supplemented by a multi-element soil standard. A Fundamental Parameters Model (Sparks 1976) was used to correct for matrix effects. This combination of standards and correction model will provide a relative error of approximately 1% in the results.

Analytical conditions	**Tube voltage**	**Current**	**Filter**	**Analysis time**
Very Light Elements	5Kv	Set by deadtime	none	150 secs
Solids (S-V)	10Kv	Set by deadtime	Aluminium	100 secs
Steels	25Kv	Set by deadtime	Thin anode (Ag)	100 secs
Medium elements	35Kv	Set by deadtime	Thick anode (Ag)	100 secs
Very heavy elements	50Kv	Set by deadtime	Copper	100 secs

Table 1. Instrumental conditions used for the analysis.

Table 2, below details the elements analysed under each analytical condition and the profiles used to identify and quantify the elements of interest. The energy peaks used for quantitative data are listed as 'A; and those used for removal of overlapping peaks are listed as 'O'. The profiles are those supplied by Oxford Instruments.

Very Light elements			
Elmt	*Line*	*Profile*	*Type*
Na2O	K	NaK05NONE3	A
MgO	K	MgK05NONE3	A
Al2O3	K	AlK05NONE3	A
SiO2	K	SiK05NONE3	A
P2O5	K	PK05NONE3	A
S	K	SK05NONE3	A
Cl	K	ClK05NONE3	O
Ag	L	AgLVLE_geol	O

Solides (S-V)			
Elmt	*Line*	*Profile*	*Type*
S	K	SK12AlTN3	O
Cl	K	ClK12AlTN3	A
K2O	K	KK12AlTN3	A
CaO	K	CaK12AlTN3	A
TiO2	K	TiK12AlTN3	A
Sn	L	SnL12AlTN3	O
Pb	M	PbM12AlTN3	O
Steels			
Elmt	*Line*		*Type*
K	K	KK15AlTK2	O
Ca	K	CaK15AlTK2	O
Ti	K	TiK15AlTK2	O
MnO	K	MnK15AlTK2	A
Fe203	Ka	FeKa15AlTK2	A
Fe	Kb	FeKb15AlTK2	O
Ni	K	NiK15AlTK2	O
Medium Elements			
Elmt	*Line*	*Profile*	*Type*
Mn	K	MnK35AgTN2	O
Fe	Ka	FeKa35AgTN2	O
Fe	Kb	FeKb35AgTN2	O
Ni	K	NiK35AgTN2	A
Cu	K	CuK35AgTN2	A
Zn	K	ZnK35AgTN2	A
As	K	AsK35AgTN2	A
Pb	La	PbLa35AgTN2	O
Pb	Lb	PbLb35AgTN2	A
Pb	Lg	PbLg35AgTN2	O
Very heavy Elements			
Elmt	*Line*	*Profile*	*Type*
Ag	K	AgK50CuTK2	A
Sn	K	SnK50CuTK2	A
Sb	K	SbK50CuTK2	A
Pb	La	PbLa50CuTK2	O
Pb	Lb+g	PbLbg50CuTK2	O

Table 2. Details of element peaks and profiles used in the analysis.

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(Statement prepared by Phil Clogg, Archaeology Department staff member, Durham University)

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